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RRTAC 90-9

Literature Review on the Disposal of Drilling Waste Solids

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LAND CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee

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Regulating surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a Chairman from Alberta Environment and two Deputy Chairmen from Alberta Forestry, Lands and Wildlife. The Council oversees a reclamation research program, established in 1978, to identify the most efficient methods for achieving acceptable reclamation in the province. Funding for the research program is provided by Alberta's Heritage Savings Trust Fund, Land Reclamation Program.

To assist with the development and administration of the research program, the Council appointed the inter-departmental Reclamation Research Technical Advisory Committee (RRTAC). The Committee consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands and Wildlife, and Environment, and the Alberta Research Council. The Committee updates research priorities, reviews research proposals, organizes workshops, and otherwise acts as the coordinating body for reclamation research in Alberta.

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REPORT #
RRTAC 90-9

LITERATURE REVIEW
ON THE DISPOSAL OF
DRILLING WASTE SOLIDS

Prepared by

Monenco Consultants Ltd.

Prepared for

The Oil and Gas Reclamation Research Program
ALBERTA LAND CONSERVATION AND RECLAMATION COUNCIL
(Reclamation Research Technical Advisory Committee)

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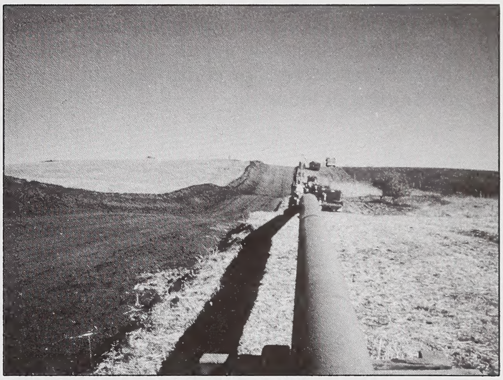

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DISCLAIMER

This report is intended to provide government and industry staff with up-to-date technical information to assist in the preparation and review of Development and Reclamation Approvals, and development of guidelines and operating procedures. This report is also available to the public so that interested individuals similarly have access to the most current information on land reclamation topics.

The opinions, findings, conclusions, and recommendations expressed in this report are those of the author(s) and do not necessarily reflect the views of government or industry. Mention of trade names or commercial products does not constitute endorsement, or recommendation for use, by government or industry.

REVIEWS

This report has been reviewed by members of the Reclamation Research Technical Advisory Committee and the Oil and Gas Reclamation Research Program Committee. RRTAC also thanks the members of the government/industry Drilling Waste Review Committee and Mr. A. Fernandes, Wastes and Chemicals Division, Alberta Environment, for their reviews.

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ABSTRACT

The Alberta Energy Resources Conservation Board is re-examining its present guidelines on drilling sump reclamation procedures. This study was commissioned to determine the extent and environmental acceptability of burying drilling waste solids produced during petroleum exploration.

A set of definitions for different burial methods was developed during the study. Data on chemical characteristics of fresh water, salt water and invert muds, as found in one specific Alberta study, are presented. The solids generally have high concentrations of soluble salts. The oil and grease content of the three mud types varied from about 4 to 8% by weight. The total heavy metal concentrations in the solids were within the normal range found in uncontaminated soils with the possible exception of molybdenum and zinc.

Legislation and policies of a number of North American jurisdictions were reviewed and were found to vary considerably. The most comprehensive guidelines are those of the State of Louisiana which place concentration limits on a number of parameters which must be achieved prior to disposal. The other extreme is Pennsylvania which has no requirements. Discussions with representatives of the Provinces of British Columbia, Alberta and Saskatchewan indicated few compliance problems.

Although burial of drilling wastes presents potential hazards with respect to surface and groundwater contamination, few incidents of contamination have been documented in the literature. The major concern with burial is the placement of hydrocarbons in an environment that does not encourage biodegradation.

Soil compaction due to the operation of heavy equipment and its effect on plant growth may be the major problem in site reclamation.

The most frequently used burial method is the mix-bury and cover technique which involves the mixing of adjacent soils with the sump contents and placement of a layer of subsoil and topsoil over the sump.

Guidelines for the treatment or disposal of drilling waste solids are being developed. These guidelines should be administered by one agency. Additional work should be conducted on the extent of migration of contaminants from existing buried sumps in order to determine the potential for soil and water contamination. A major recommendation is for increased effort in the promotion and practice of the four R's (reduce, reuse, recycle and reclaim). A number of states in the U.S. have been identified which have comprehensive regulations for the disposal of drilling wastes. Some of these states should be contacted for further information.

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1. INTRODUCTION

This study reviews the Canadian and selected international literature to determine the environmental acceptability of burying drilling waste solids produced during petroleum exploration and production.

Wastes generated by drilling activities in the oil and gas industry are receiving considerable attention with respect to disposal practices. Environmental impacts associated with the disposal of drilling wastes depend on the characteristics of the waste, the disposal method and the disposal site location. In Alberta, the Energy Resources Conservation Board (ERCB) and a government/industry committee are re-examining the current guidelines for drilling waste disposal with a view to formulating new guidelines. The present guidelines, Interim Directive No. 1D-OG 75-2 (ERCB 1975), do not address the disposal of drilling waste solids (or on-lease disposal).

In the United States, various local, state and federal regulatory agencies are imposing more stringent regulations concerning the disposal of drilling wastes. The U.S. Environmental Protection Agency is re-evaluating the current exempt status of oil and gas exploration and production waste from the hazardous waste laws.

In Alberta, drilling waste solids can be disposed of either by burial, trenching or land treatment. Some sectors of the industry and government are moving away from burying drilling waste solids in sumps as a result of concerns regarding groundwater contamination and the low rate of degradation of organics in the buried state.

1.1 Objective

The objective of this study as specified in the Request for Proposal was to review the international literature to determine the environmental acceptability of burial of drilling waste solids produced during petroleum exploration and production.

The project budget and scope did not allow review of literature world wide. Emphasis was placed on information from Canada and selected states in the United States.

1.2 Definition of Terms and Burial Practices

A lack of uniformity in the description of various burial methods was observed during the course of this study. The following definitions evolved through discussions with government and industry personnel. These definitions are designed to satisfy the majority of opinions, but also adequately separate the different methods. For the purpose of this study, burial is defined as the complete covering of the drilling solids with uncontaminated material. **The methods defined below are not necessarily in use or approved in Alberta.**

1.2.1 Drilling Waste Fluids

Drilling waste fluids, also referred to as drilling waste muds, are defined as a heterogeneous mixture of water, drilling muds, borehole cuttings, additives and various other wastes that are specifically related to the actual drilling activity.

1.2.2 Drilling Waste Solids

Drilling waste solids consist of the bottom layer of sump material and are comprised of drill cuttings, flocculated bentonite, weighting materials and other additives. Drilling waste solids can be stacked with minimal or no outflow of liquid.

1.2.3 Capping

Capping refers to the burial of undisturbed sump contents. Sump contents are left in place and a layer of subsoil is carefully placed over the contents, which remain essentially undisturbed. Topsoil is then spread to cover the capped sump area. Two variations are used:

1. sump contents are left undisturbed in the sump except for settling and evaporation. A layer of subsoil is then placed carefully over the contents, followed by a cover of topsoil. If the liquid portion is excessive, the displaced liquid can be collected in a small excavated pit; or

2. sump contents are flocculated and the liquid layer is decanted and disposed in an approved manner. The remaining solids are then left undisturbed and covered with about one metre of subsoil and then a layer of available topsoil.

1.2.4 Mix, Bury and Cover

Sump contents are stabilized and diluted by mixing with native excavated material. This method is also referred to as mud mixing or dilution-burial. A number of variations are used. The following situations assume that there is some stockpiled subsoil and topsoil available (e.g., from the excavation for the sump):

1. following removal of the liquid portion, sump contents are spread on adjacent subsoils to dry. After drying, the sump contents and subsoil are mixed and bulldozed back into the sump. A layer of subsoil, followed by topsoil is spread over the area; or,
2. following removal of the liquid portion, the sump contents are mixed, within the sump, with subsoil from stockpiles to provide a density of contents that will support a person. A minimum of one metre of subsoil is placed over the mixture followed by a layer of topsoil; or,
3. sump contents are squeezed and mixed in several pits, in sequence. The mixture in each pit is covered with a layer of subsoil followed by a layer of topsoil; or
4. sump contents are mixed within the sump, with underlying subsoil to a depth of up to 10 metres. The stockpiled subsoil is placed over the mixed contents to an approximate depth of 3 metres. This method is common to salt saturated drilling fluids and is termed 'deep burial'.

1.2.5 Trench

A back-hoe is used to construct deep, narrow trenches, confined to the lease area. Trench configuration is variable depending on the surface area available for trenching. One configuration consists of trenches radiating from the sump. Another consists of lateral trenches extending from a header trench. Liquids or solids are squeezed out of the sump as stockpiled soils are slowly introduced into the sump to displace contained liquids or solids which flood into the trenches. Soil excavated from the next trench is cast on top of the material in the active trench resulting in dilution and stabilization. This method is not practiced or allowed in the "White Area" of the province (pers. comm. D. Lloyd, Manager, Industrial Land Use Branch, Public Lands Division, Alberta Forestry, Lands and Wildlife, 1990).

1.2.6 Encapsulation

This method involves the total containment of the decanted sump contents by using low permeability liners. These liners can be clay liners with a permeability of 1×10^{-7} cm/s, or less, or an approved synthetic liner. For clay liners, compaction of native clay may be required to achieve the 1×10^{-7} cm/s permeability.

After treatment and decanting of the liquid layer, the remaining solids are capped by one metre of compacted material. Finally, subsoil and topsoil are spread over the encapsulated area.

1.3 Other Methods of Disposal

The prime objective of this study was to review the environmental acceptability of burial of drilling waste solids. However, for completeness, this section describes, in brief, alternative disposal methods which are in common use today.

1.3.1 Land Treatment (Landfarming)

The definition and use of this term is inconsistent. The term has been generally applied to the continuous treatment of oil refinery wastes on a dedicated area of land which is managed in a manner which optimizes the soil system to degrade, transform and assimilate the waste constituents.

This definition was developed at a Canadian Petroleum Association, ERCB, Alberta Environment Workshop on Petroleum Industry Wastes at Red Deer in 1989 (pers. comm. J. Fujikawa, Soil Protection Branch, Alberta Environment, 1990). The aim of land treatment is not contaminant dilution, nor a means of transferring contaminants from one medium, such as soil, to another such as air or water. Land treatment must ensure that surface water and groundwater quality is not affected. Land treatment should not result in soil quality degradation requiring cleanup and reclamation, or land use restrictions.

In accordance with the definition given above, this method would not apply to the disposal or treatment of drilling solids on an on-site basis. The term "land spreading" has been adapted to describe the current practice of disposal and/or treatment of drilling wastes on-site.

1.3.2 Land spreading

Land spreading is a dilution measure. the sump contents are spread over a pre-determined land surface area based on an acceptable loading rate. the waste may be spread on the topsoiled surface or cultivated into the subsoil and then covered with topsoil. a vegetative cover must be established within a year or two. land spreading is typically a one time effort and the entire process may require 6 to 12 months.

1.3.3 Landfilling

Landfilling is an off-lease method involving disposal of solids at an approved landfill. for class ii industrial landfills, wastes containing liquid hazardous waste or hazardous wastes containing free liquids, as well as other hazardous wastes prohibited by regulation from landfill disposal are excluded. disposal at a municipal landfill is allowed only after acquiring approval from the public health board.

1.3.4 Incineration

Incineration is a disposal option for diesel invert mud residues and cuttings. Becker (1986) reported promising developments in incinerators for oily sludges and cuttings at remote sites. Initial design of a portable rotary kiln unit produced satisfactory stack effluents and cuttings, but lacked adequate throughput. Subsequent development of a stoker type unit resulted in significant performance improvement over the rotary kiln type.

Recent testing has been done in Alberta, but equipment development and economics need further study. Incineration should be considered as a treatment method only, as non-organic contaminants still must be addressed (pers. comm. R. Byers, Gulf Canada Resources, 1990).

1.3.5 In-Situ Solidification/Fixation

Solidification/Fixation changes the structural properties, permeability and leaching characteristics of a waste such that it may be disposed of in environmentally acceptable form. According to Calloway (1986) solidification is a process which chemically and/or physically changes a fluid (liquid or gas) into a solid. Fixation is a process which chemically and/or physically changes a material such that its final leaching characteristics are more accepted for disposal. Gypsum and fly ash are common materials used in treating drilling muds. Typical improvements following fixation are:

1. increases in unconfined compressive strength from: $<0.13 \times 10^{-6}$ N/m^2 to 6.89×10^{-6} N/m^2.
2. decrease in permeability from 1×10^{-5} cm/s to $<1 \times 10^{-7}$cm/s.
3. improvement in leachate quality; in some cases a hazardous waste is converted to a non-hazardous product.

One disadvantage of solidification is the resulting increased volume which increases the handling costs.

1.3.6 Road Application

With approval from regulatory authorities, drilling waste solids may be incorporated into road beds as a method of disposal. Typically, this method involves salt-based drilling wastes previously spread on-lease to dry. The dried material is then collected and mixed with road bed construction material. This method was evaluated and assessed by the ERCB and is no longer considered as a disposal alternative.

1.3.7. Alkali Slough

Freshwater gel and salt-based drilling mud wastes can be disposed of in self-contained alkali sloughs, provided groundwater is not affected. In 1985, two alkali slough disposal operations were reported to be in operation in the Estavan area of Saskatchewan (Gossard 1985). They received waste from seven salt-based mud systems over a 1.5 year period without apparent groundwater contamination or other environmental problems. This method of disposal is not practiced in Alberta.

2. CHARACTERIZATION OF DRILLING WASTE SOLIDS

The preferred method of burial is often dictated by the characteristics of the wastes. The following section briefly addresses: the types of mud systems currently in use in Alberta; the additives used to modify and enhance the performance of the drilling fluid; and, the chemical characteristics of drilling solids generated in four regions of Alberta.

2.1 Drilling Mud Systems

Three basic types of drilling mud systems are currently in use by the petroleum industry in Alberta. They are categorized as freshwater gel, salt water (KCl and NaCl) or oil invert-based mud systems. In general, freshwater gel type sumps account for 70% to 80% of the sumps constructed annually, while salt water and invert sumps account for 20% to 25% and 10%, respectively.

The freshwater gel based system is the most economical. It is typically used where temperature and pressure are not excessive and where saline or water sensitive formations are not encountered. This system is most commonly comprised of water, bentonite (gel) as a viscosifier, carboxymethyl cellulose for fluid loss control, lignosulfonates as thinners, and polymers for increased yield (Leskiw et al. 1987).

The salt water based system is used for drilling through water sensitive formations and where rock salt, prairie evaporites or salt water flows are encountered. Composition is 20 000 to 40 000 ppm salts (KCl or NaCl) in a water-bentonite-polymer medium with oxygen scavengers to inhibit corrosion (Leskiw et al. 1987).

The oil invert-based system is the most expensive. This system is used when drilling encounters high temperatures and pressures and the need for shale stabilization arises. The major components are diesel fuel (i.e., up to 50% by volume), emulsifying agents, weighting agents, usually barite for pressure control, organophillic clay as viscosifier and calcium chloride in concentrations of 300 000 ppm (Leskiw et al. 1987).

2.2 Drilling Mud Additives

The general functions of drilling muds (Berger and Anderson 1981) are:

1. to remove and transport cuttings from the bottom of the hole to the surface;
2. to lubricate and cool the bit and drillstring;
3. to wall the borehole with an impermeable cake;
4. to counteract encountered subsurface pressures;
5. to suspend cuttings during times when fluid circulation is stopped;
6. to support part of the weight of the drillstring;
7. to minimize any adverse effects upon the formation adjacent to the borehole; and
8. to transmit hydraulic horsepower to the bit.

To accomplish these various functions, additives are incorporated to modify and enhance the performance of a drilling mud. Numerous additives are available for this purpose. Table 1 lists some general types of drilling mud additives; these include weighting materials, viscosifiers, thinner dispersants, filtrate reducers, lost circulation materials, alkalinity/pH controls, emulsifiers, surfactants, corrosion inhibitors, defoamers, flocculants, biocides, lubricants, calcium removers, and shale control inhibitors.

2.3 Some Chemical and Physical Properties of Drilling Waste Solids

The physical and chemical characteristics of drilling solids are not well documented. One detailed characterization study was conducted by Macyk et al. (1990). The sampling program included a total of five sample points or horizontal positions where three depths at each position were sampled in both the liquid and solid phases of a given sump. Specific details for sample preparation and analyses are given in Macyk et al. (1990). The saturated paste extract was analysed for pH, electrical conductivity,

Table 1. Drilling Mud Additives (Beal et al. 1987)

Function	General Purpose	Common Additives
Weighting Material	Control formation pressure, check caving, facilitate pulling dry pipe & well completion operations.	Barite, lead compounds, iron oxides.
Viscosifier	Viscosity builders for fluids, for a high viscosity-solid relationship.	Bentonite, attapulgite clays, all colloids, fibrous asbestos.
Thinner Dispersant	Modify relationship between the viscosity and percentage of solids, vary gel strength, deflocculant.	Tannias (quebracho), polyphosphates, lignitic materials.
Filtrate Reducer	Cut the loss of the drilling fluid's liquid phase into the formation.	Bentonite clays, sodium carboxymethyl cellulose (CMC), pregelatinized starch, various lignosulfonates.
Lost Circulation Material	Primary function is to plug the zone of loss.	Walnut shells, shredded cellophane flakes, thixotropic cement, shredded case fiber, pig hair, chicken feathers, etc.
Alkalinity/pH Control	Control the degree of acidity or alkalinity of a fluid.	Lime, caustic soda, bicarbonate of soda.
Emulsifier	Create a heterogeneous mixture of two liquids.	Lignosulfonates and detergent, petroleum sulfonate.
Surfactant	Used to control the degree of emulsification, aggregation, dispersion, interfacial tension, foaming, and defoaming (surface active agent).	Include additives used under emulsifier foamers, defoamers, and flocculators.

continued...

Table 1. (Concluded)

Function	General Purpose	Common Additives
Corrosion Inhibitor	Materials used to decrease the presence of such corrosive compounds as oxygen, carbon dioxide, and hydrogen sulfide.	Copper carbonate, sodium chromate, chromate-zinc solutions, chrome lignosulfonates, organic acids and anise polymers, sodium arsenite.
Defoamer	Reduce foaming action especially in salt water based muds.	Long chain alcohols, silicones, sulfonated oils.
Foamer	Surfactants which foam in the presence of water and thus permit air or gas drilling in formations producing water.	Organic sodium and sulfonates, alkyl benzene sulfonates.
Flocculants	Used commonly for increases in gel strength.	Salt, hydrated lime, gypsum, sodium tetraphosphates.
Bactericides	Reduce bacteria count, avoid corrosion and plugging.	Starch preservative, paraformaldehyde, caustic soda, lime, sodium pentachloraphenate.
Lubricants	Reduce torque and increase horsepower at the bit by reducing the coefficient of friction.	Graphite powder, soaps, certain oils.
Calcium Remover	Prevent and overcome the contamination effects of anhydrite and gypsum.	Caustic soda (NaOH), soda ash, bicarbonate of soda, barium carbonate.
Shale Control Inhibitors	Used to control caving by swelling or hydrous disintegration.	Gypsum, sodium silicate, calcium lignosulfonates, lime, salt.

chloride and other metals (i.e., Na, K, Ca, Al, Cr, Fe, V, Ti, Cd, Cu, Pb, Zn Mn, Mg, Li, Sr, B, Ba, P, S, Mo, Ni, Se, As, Co and Si). DTPA-NH_4HCO_3 extractable Fe, Cd, Cu, Pb, Zn, Mn, Ca, Mg, Na, K, B, P, Mo, Ni and Se were determined to indicate the potential availability to plants. Total elemental analysis of the sump solids was also performed.

The following information is abstracted from the extensive study conducted on drilling mud wastes produced in the Cold Lake, Foothills, Grande Prairie and Slave Lake regions of Alberta (Macyk et al. 1990). Data most pertinent to this study, which include saturated paste extract values, are condensed in Table 2.

pH values of sump solids ranged from 7.7 to 9.6, with the lower values associated with the invert muds. Electrical conductivity values (EC) were considerably lower in the freshwater gels than the other mud formulations which had extremely high values. The KCl and NaCl muds had the highest chloride concentration. The soluble calcium concentrations of the KCl and NaCl muds were the highest, followed by the invert mud, with the freshwater muds much lower. This indicates that soluble calcium is present in the KCl and NaCl additives.

The sodium concentration in the freshwater gel was relatively high compared to non-sodic soils. The potassium concentration is significantly higher in the KCl muds than the other three muds. The SAR data show that the SAR values of the freshwater gel can exceed those of the other muds. This is due to the fact that the calcium concentration of the other muds exceeds that of the freshwater mud. The SAR value describes the ratio of sodium to calcium and magnesium; a high calcium value will reduce the SAR value. A few of the soluble trace metal concentrations (Al, Sr, Cu and Ba) were considerably higher in the invert mud extract than in the other mud types.

Although the oil content was variable, the freshwater, KCl and NaCl muds had less oil (<4%) than the invert mud (up to 7.7%). The variable clay content is likely related to the amount of bentonite in the mud.

Table 2. Range of Mean Values for Saturated Paste Extract for Solids.

Waste Type	No. of Sites	pH	EC (dS/m)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SAR	Al (mg/L)	Sr (mg/L)	Cu (mg/L)	Ba (mg/L)	Oil (%)	Clay (%)
Freshwater	6	8.2-9.6	2.7-12.8	80-1230	6-405	0.7-27	727-4320	11-98	25-279	0.6-5.2	0.14-3.23	0.01-0.05	0.02-0.23	0.04-2.16	10-66
Invert	2	7.7-8.8	38.9-43.9	1970-21500	8240-8410	10-150	3090-3550	258-361	9-11	15.8-17.4	63-119	0.15-0.38	2.4-5.9	3.6-7.7	16-19
KCl	2	8.2-8.6	50.2-111	18300-61000	1150-2040	21-166	4820-10000	12500-36900	34-78	3.2-5.0	10-49	0.005-0.06	0.09-0.43	1.6-3.8	22-33
NaCl	2	8.2-9.3	49.6-156	28600-98800	2190-3370	13-290	12300-57900	177-431	52-338	5.2-7.0	5-50	0.001-0.09	0.16-0.33	0.2-0.6	15-18

Adapted from Macyk et al. 1990.

The total concentration of a large suite of trace elements did not differ greatly with respect to the type of mud. Total analyses indicated that mean values were within the normal range found in soils, with the exception of sodium, potassium, magnesium, molybdenum and zinc.

In conclusion, it appears that the predominantly used freshwater mud system would have the least adverse impact on the environment as compared to the salt and invert mud systems. The freshwater systems have the lowest soluble salt concentrations and relatively low hydrocarbon content. Total metal contents are within the range of normal soils, with the possible exception of molybdenum and zinc.

The information discussed in this section should be considered if comprehensive guidelines or regulations with respect to drilling solids disposal are formulated. The characteristics of drilling mud systems will determine appropriate burial locations and methods.

3. LEGISLATION AND POLICIES

This section contains an abstracted review of rules and regulations with respect to the location, construction, permitting and reclamation of drilling sumps. This review is largely restricted to the disposal of the solid wastes within the pit itself, associated trenches, or sequential pits immediately adjacent to the pit. Limited reference is made to off-site disposal. This review includes the regulations, guidelines, and directives issued by the Provinces of Alberta, British Columbia, Saskatchewan, numerous States in the U.S.A., both American and Canadian Federal Governments and the Petroleum Industry.

3.1 The Province of Alberta

3.1.1 Alberta Energy Resources Conservation Board

As of January 1990, there were two regulations addressing the disposal of oil and gas pit contents. The ERCB's (1975) INTERIM DIRECTIVE NO. ID-OG-75-2 is restricted to the disposal of sump fluids off lease only and does not refer to the solids retained after fluid removal; therefore, details of the regulation are not discussed here. The ERCB's (1981) INTERIM DIRECTIVE NO. ID-81-1 is restricted to subsurface disposal of fluids.

Present ERCB regulations state that an operator of a sump pit must obtain approval from an appropriate regulatory representative for any off-lease disposal of drilling fluids. The responsibility for this lies within Alberta Forestry, Lands and Wildlife for sites on public lands and the ERCB on private lands. The Drilling Waste Review Committee is presently updating and revising these regulations.

3.1.2 Alberta Forestry, Lands and Wildlife

3.1.2.1 Alberta Forest Service. The Alberta Forest Service is one of two divisions within the Department of Forestry, Lands and Wildlife responsible for managing Crown-owned land in the province. The Alberta Forest Service manages all Crown land within the Green Area. They are responsible for safeguarding the land surface against environmental damage and for enforcing the ERCB regulations pertaining to oil well sump waste disposal on forested Crown land.

An unofficial directive does address the handling of high salt or invert mud system solids to some extent. It suggests that after treatment and removal of the clarified fluids, the remaining solids must be applied to the land surface at a predetermined loading rate which permits normal regeneration of vegetative communities. In the case of invert cuttings, the material can be mixed into surface soils on the lease. The Alberta Forest Service inspects sites to assess the quality of reclamation.

3.1.2.2 Public Lands Division. The Public Lands Division of Alberta Forestry, Lands and Wildlife is responsible for managing all Crown-owned land within the White Area of the province. This division is responsible for protection of the land surface from environmental damage and is therefore responsible for enforcing ERCB regulations which pertain to sump waste disposal on Crown land. As stated previously, these regulations are restricted to drilling liquids only. However, the Public Lands Division includes solids in their interpretation of the ERCB Directive, particularly if the material leaves the site. As with the Alberta Forest Service, the Public Lands Division is also discouraging in-pit burial and deep trenching waste disposal methods. Public Lands' emphasis is on surface treatment methods (pers. comm. D. Lloyd, Manager Industrial Land Use Branch, Public Lands Division, Alberta Forestry, Lands and Wildlife 1990). They are active in site inspections to determine reclamation quality.

3.1.3 Alberta Environment

3.1.3.1 Wastes and Chemicals Division. This division is not involved with disposal of oil well drilling wastes unless the waste generator decides for on-site landfilling for large volumes of drilling solids. Off-site disposal of drilling solids which do not conform with the CGSB leachate extraction procedure No. 164-GP-1 MP (Transport Canada 1987) has to be to a Class II industrial landfill. The decision is ultimately up to the Provincial Board of Health. If the material does not pass the leachate test it must be transported to a secure, approved landfill (of which there are only a few in the Province). If the material passes this test, it can be legally disposed of in any landfill provided the landfill operators will accept it. Disposal in municipal or secure landfills is not practiced to any great extent.

3.1.3.2 Land Reclamation Division. The operator of a sump pit must obtain a "reclamation certificate" from the Land Conservation and Reclamation Council under the provision of the Alberta Land Surface Conservation and Reclamation Act (Government of the Province of Alberta 1984). This application will be followed by a site inspection to determine whether the land is reclaimed in a satisfactory manner. This inspection is related to the total well site area and is not restricted to the sump disposal area. A reclamation certificate may be issued if the site is considered adequately reclaimed. In cases where reclamation of the entire site is considered inadequate, the Council may conduct an inquiry. At, or following an inquiry, the Council may, if it considers it necessary to do so, issue a reclamation order. The expenses incurred as a result of the remedial work constitute a debt payable to the Crown by the persons to whom the reclamation order was directed.

3.1.4 Reclamation

In Alberta, the land use and acceptable vegetative species of reclaimed drill sites vary according to land ownership and locations in Alberta.

1. Previously Cultivated Areas - The area is usually managed as a part of the surrounding field.
2. Native Rangeland - The area is either seeded to a drought resistant grass mix, or in the case of private rangeland, to the species requested by the landowner.
3. Green Area - There are several options: 1) seed to an approved grass mixture, 2) leave to revegetate naturally to encroaching species, or 3) plant to forest species.

3.1.5 Safety

There are no specific requirements with respect to safety. Fencing of the drill site is the prerogative of the drilling contractor or as requested by the landowner. Generally, drilling sites in populated or livestock grazing areas are fenced. If fenced, the fences are not removed until a Reclamation Certificate is issued or as requested by the landowner.

3.1.6 Compliance Problems

Compliance problems do occur with respect to the operation and reclamation of drilling sites. Compliance problems generally involve soil slumping over the back filled sump, irregular micro-topography and plant growth inhibition. These problems however, may or may not be the result of sump related activities and could be the result of poor reclamation practices. More work is required to differentiate sump related activities from reclamation practices. In a few cases, burial of invert muds has resulted in migration of toxic components through the groundwater system (pers. comm. H. Lillo, Manager Environment Protection Dept. ERCB 1990). The problems typically arise from negligence. The lack of detail in the present

ERCB directive has also resulted in compliance problems. These problems should be addressed when the new directive is finalized and comes into force. To date, the ERCB and other Government agencies have generally been successful in obtaining compliance.

3.2 Canada

3.2.1 Federal

Guidelines for well sites in northern Canada were published by the Ministry of Indian Affairs and Northern Development (1986). Only those facilities immediately associated with the well site (rig site, drilling fluid sumps and campsites) were addressed. This document focuses on the conditions associated with continuous and discontinuous permafrost.

Prior to any construction activity, a Land Use Permit must be obtained from the local Indian and Northern Affairs office. The application must include a plan for fuel and hazardous waste spills, solid waste management, forest fires and reclamation. The permit requires a description of a number of considerations, such as surface drainage conditions, avoiding active stream channels, high water tables and groundwater seepages. There must be adequate space to accommodate sumps. In non-permafrost areas, if the sump is in permeable materials, it must be lined with clay or a liner (e.g., plastic). Drilling fluid sumps must be located a minimum of 100 m from the normal high water mark of any permanent water body or stream.

These guidelines do not differentiate between drilling fluids and solids. This suggests that there is no requirement for separation of these materials. Essentially, the reclamation process involves the gradual addition of stored backfill material until the mixture is as solid as possible. When the mixture has reached this consistency, the surface is capped with clean material and contoured. This method is similar to the "mix, bury and cover" method (Section 1.2.4).

An alternative method, referred to as "trenching" (Section 1.2.5) involves filling trenches, which radiate from the sump, with liquids and solids. These trenches are then covered with soil.

Oil and gas wells drilled on Indian Reserves must conform to the regulations of the province in which the reserve is located.

3.2.2 Other Provinces

3.2.2.1 Province of Saskatchewan. Saskatchewan wells are usually drilled with freshwater drilling muds. In the past the mud was spread on-lease, however, this practice has been recognized as detrimental to crop growth. The Government of Saskatchewan policy as of 1985 is as follows (Gossard 1985):

1. mud must be allowed to settle and the water portion disposed to deep disposal wells; and
2. the mud cuttings must be buried on-lease with a minimum of eight feet of cover, or the waste can be disposed of in an alkali slough, provided the slough is self-contained and this practice is landowner approved; also, groundwater is not to be affected and no oil can enter the slough.

3.2.2.2 Province of British Columbia. In January 1990, the B.C. Energy Resources Division (British Columbia Ministry of Energy, Mines and Petroleum Resources 1990) issued a document entitled "Guidelines for Construction and Cleanup of Roads, Leases and Seismic Lines in Petroleum Exploration Areas". Section VI of the document outlines in detail the procedures for lease cleanup approval. Before submitting a cleanup proposal, a chemical analysis and fish bio-assay test must be performed on drill sump fluids by a recognized commercial laboratory. Lease clean-up methods, stipulated in Section VII of the document do not allow for deep and shallow trenching as suitable methods. Disposal of KCl and invert mud system is acceptable if either downhole disposal or disposal at a recognized waste treatment plant is practiced. At the time of writing, British Columbia does not have a suitable waste treatment plant.

Alternatively, a burial practice termed 'trap and mix' is described step by step. The advantages of this method are:

1. subsoil, sump fluids and sludge are all intermixed, encouraging microbial detoxification to take place;
2. mixing up the sludge layer (mostly bentonite) helps to avoid the "impermeable lens" effect;
3. it allows good compaction of all material and uses less area for disposal resulting in less sump settlement; and
4. it can be used during the winter.

The disadvantages are:

1. the sump must have at least 40% freeboard; otherwise the sump must first be enlarged prior to the start of cleanup; and
2. the operator of the sump pit must ensure the sump mixes thoroughly.

A final recommendation is to build a mound over the sump after completion of initial cleanup to compensate for any settling and subsidence.

3.2.3 Compliance Problems

The Saskatchewan Department of Energy and Mines has not recorded any complaints with respect to drilling wastes and field inspections have not revealed any problems (pers. comm. J. Gossard, Director, Petroleum Development Branch, Petroleum and Natural Gas Division, Saskatchewan Energy and Mines, 1990). Most of the wells in Saskatchewan are drilled with a freshwater gel mud, except for the southwestern part of Saskatchewan where salt water gels are often used. Although there have been no complaints, the Department has still expressed concerns over compliance problems. Invert muds which are seldom used in Saskatchewan are spread on roads.

No major compliance problems have been encountered in British Columbia. Drilling operations and disposal procedures are monitored methodically so problems appear to be remedied promptly.

A study by French (1978) showed that 30% of 47 abandoned well sites in the Mackenzie Delta and Arctic Islands experienced problems related either directly or indirectly to sumps and/or the containment of waste drilling fluids.

3.3 United States of America

3.3.1 State Regulations

The following is abstracted from an American Petroleum Institute review of Federal and State Regulations for the Oil and Gas Industry (American Petroleum Institute 1987).

Alabama - State Rules and Regulations appear to apply primarily to fluids. "Pits are closed by dewatering, then backfilling, levelling and compacting".

Alaska - Proposed regulations define drilling wastes as "drilling muds, cuttings, hydrocarbons, brine, acid, sand and emulsions of mixtures of fluid produced from, and unique to, the operation or maintenance of a well".

State statutes require permits for solid waste disposal facilities. The general construction requirements state that the pits must be rendered "impervious", however, there is no specific requirement for a lining. Proposed Department of Environmental Conservation regulations would impose specific construction requirements for reserve pits. These requirements would depend on a number of factors (i.e., proximity to surface and groundwater, proximity to a population centre, or permafrost conditions). Under 1986 rules, solid waste permits are required for closure and for discharges.

Arizona - Pits are allowed to evaporate before closure and are then filled. This method is considered acceptable due to the arid nature of most of the state.

Arkansas - The State does not have any specific regulations governing the construction or management of reserve pits or the disposal of drilling wastes. The Pollution Control and Ecology Department has been sending out letters of authorization intended to serve as informal permits. These letters stipulate management practices for reserve pits and disposal of drilling wastes and all earthen pits must be lined with a synthetic liner or a clay liner (18 to 24 inches thick). The section on disposal of drilling wastes emphasizes fluids only.

Off-site disposal of reserve pit fluids and drilling mud requires a permit from the Arkansas Department of Pollution Control and Ecology. The permit requires an analysis of the fluids and the drilling mud, the amount hauled and the landowners agreement. The drilling mud analysis will include tests for chromium, zinc, chlorides and pH.

California - Ten agencies regulate the oil and gas activity in California. Generally, the operator of a sump pit must either remove all wastes from the sump, or remove all the free liquid from the sump and cover solid and semi-solid wastes provided they do not contain hazardous materials. However, most muds used in California do not fall under this provision. The Department of Health Services will review test data on new muds in order to determine whether they are non-hazardous. Again, most of the regulations are directed towards the liquid portion of sump contents.

Colorado - The State requires that, "before commencing to drill, proper and adequate slush pits shall be constructed for the reception and confinement of mud and cuttings, and to facilitate the drilling operation. Special precautions shall be taken to prevent contamination or pollution of state waters".

According to the Oil and Gas Conservation Commission, most wells are drilled using tanks rather than reserve pits. Most drilling fluids and muds in Colorado are bentonitic and freshwater based. Very few oil-based fluids are used and these are recycled until finally disposed of into an approved landfill. Generally, after fluid removal, the sludges are dried and disposed of on the surface by incorporation into the soil. The sludges may also be buried when the pit is backfilled.

Florida - Drilling fluids are put into pits during operation, but are disposed of by injection. Pits are nearly dry when they are backfilled.

Illinois - There are no requirements stating that drilling pits must be permitted or lined. Fluids may be disposed of in a dry hole. When the pit muds dry, the pit is backfilled and reclaimed. Pits must be reclaimed within six months after drilling ceases.

Indiana - The general practice is to pump the small amount of fluid in the pit to the surrounding land, bury the drill cuttings and muds, and reclaim the land.

Kansas - On-site burial is the primary method. In geologically sensitive areas, sealed drilling pits or portable pits may be required and in-situ disposal of drilling pit contents may be prohibited. Conditions and criteria governing these requirements are unclear. Liners are not required for drilling pits unless the State determines a liner is necessary to protect soil or water resources in sensitive areas.

Kentucky - Statutes provide protection concerning solid waste control. Statutes prohibit direct or indirect contamination of State waters caused by any pollutants. Solid waste control includes oil and gas drilling muds and oil production brine. These materials are considered special wastes of high volume and low hazard.

Pit construction requirements are imposed on the oil and gas operators through a permit mechanism. All holding pits must be designed and constructed with an impermeable synthetic liner at least 20 mils thick, a solid berm at least 0.6 m (2 ft) deep and a freeboard of at least 0.3 m (1 ft). Road spreading or land spreading of produced fluids in Kentucky is prohibited. When any pit is taken out of service, it must be backfilled and the land restored.

Louisiana - Reserve pits do not have to be lined. Reserve pit fluids may be disposed of on-site providing applicable technical criteria are met. For either land treatment, burial or trenching, waste/soil mixtures must not exceed the following:

pH	6 to 9
Arsenic	10 ppm
Barium	2 000 ppm
Cadmium	10 ppm
Chromium	500 ppm
Lead	500 ppm
Mercury	10 ppm
Selenium	10 ppm
Silver	200 ppm
Zinc	500 ppm
Oil & Grease	1%
Electrical Conductivity (wet lands)	<8 mS/cm
Electrical Conductivity (uplands)	<4 mS/cm
Sodium adsorption ratio	<14 (wetlands)
Sodium adsorption ratio	<12 (uplands)
Exchangeable sodium %	<25 (wetlands)
Exchangeable sodium %	<15 (uplands)

Pits may be closed by mixing the waste with soil and burying the mixture on-site if it meets the above limits, has a moisture content of less than 50% by weight, an EC of less then 12 mS/cm, and an oil and grease content of less than 3% by weight. The top of the burial site must be at least 1.5 m (5 ft) below ground level and covered by native soil. The bottom of the pit must be 1.5 m (5 ft) above the seasonal water table.

Pits may be closed by solidification and on-site burial, using the same cover and depth requirements, if they have a pH of 6 to 12, and do not exceed the following limits in standard leachate tests:

Oil and grease	10.0 mg/L	Lead	0.5 mg/L
Arsenic	0.5 mg/L	Mercury	0.02 mg/L
Barium	10.0 mg/L	Selenium	0.1 mg/L
Cadmium	0.1 mg/L	Silver	0.5 mg/L
Chromium	0.5 mg/L	Zinc	5.0 mg/L

The solidified material must also meet permeability, compressive strength and wet/dry durability criteria (not given).

Reserve pit contents can be transported off-site to permitted commercial land treatment or pit disposal facilities.

Michigan - The current required practice is for the fluids in the drilling pits to be pumped off prior to encapsulation of the pit solids. The remaining mud pit solids may be required to be mixed with earthen materials. The residue is encapsulated and buried on-site or removed to an approved waste disposal site. For on-site disposal, the edges of the pit liner must be folded over the pit and a separate piece of 10 mil virgin PVC is required to encapsulate the pit. The top of the cover must be buried at least 1.2 m (4 ft) below grade.

Solid drilling wastes may be disposed of in an approved, licensed, solid waste landfill, with the agreement of the landfill operator.

Mississippi - Four options are detailed. First, the use of drilling reserve or mud pits is included in the drilling permit. When closing the reserve pit, there are several options for drilling mud disposal. If the well is a dry hole, the muds must be pumped back into the hole before plugging, provided the surface casing has been set to a point below the base of the United States Drinking Water (USDW) depth limitations. The second option is landfarming. (Landspreading as defined in this report). The third option is to haul to a commercial disposal facility. The fourth option is to treat the in-pit muds with flocculants. The supernatant water is discharged and the dewatered muds are covered in place and the pit is closed.

Missouri - There are no regulations related to drilling pits. Drilling pits are not lined. When pit muds dry, they are buried on-site.

Montana - The Oil and Gas Conservation Division requires the operator of a sump pit to "contain and dispose" of drilling operation wastes either by removal from the site or burial at least 0.9 m (3 ft) below the surface of the land. The operator is also required to "construct his reserve pit in a manner adequate to prevent undue harm to the soil or natural water in the area. When a salt base mud system is used as the drilling medium, the reserve pit shall be sealed when necessary to prevent seepage".

Nebraska - A permit is required for retaining pits which are lined or constructed with impermeable material when the underlying soil conditions would permit seepage to reach subsurface freshwater zones. The regulations do not address any requirements for reserve pits. When drilling is complete, the supernatant in mud pits is allowed to evaporate. After the mud pit has dried, the residues are spread on land, and the pit is backfilled.

New Mexico - The reserve pit contents are dried out through evaporation, and the dried muds buried. In New Mexico, annual evaporation exceeds precipitation in a ratio of about 5 to 1. Removal of drilling fluids or drill cuttings for off-site disposal must be approved by an appropriate official from the regulatory agency.

New York - The majority of wells are drilled with air and there is very little fluid or mud produced. Therefore, the regulations do not address sump fluid or solids disposal.

North Dakota - Before drilling activities begin, a State inspector surveys the site for pit location and decides if a liner is required. Pit restoration requires approval from the State. Restoration includes redistribution of topsoil removed during construction.

Oklahoma - The State requires a soil or geomembrane liner for high chloride pits located in a hydrologically sensitive area. A geomembrane liner is required for all oil based fluids. The contents of the sump can be disposed of by evaporation and backfilling, solidification, hauling to a permitted commercial pit, or a permitted recycling facility.

Trenching of the contents of any reserve or circulation pit is prohibited when the pit fluids contain chlorides in excess of 5 000 mg/L and the pit is located over a hydrologically sensitive area. Trenching is also prohibited, regardless of the chloride contents of the fluids if treatable water is found within 1.8 m (6 ft) of the base of the pit.

Closure procedures for any noncommercial pit shall include a minimum of 0.9 m (3 ft) of soil cover over any geomembrane cap or any remaining pit contents, with all stockpiled topsoil being applied last. The materials should be mounded or sloped to encourage runoff.

Ohio - Earthen pits may be used to contain substances resulting from drilling operations. There are no requirements for liners, unless prescribed on a site-specific basis in areas identified as hyrogeologically sensitive.

The regulations specify that "muds", cuttings and other wastes should not be disposed of in violation of any rule. In most cases, pit solids are buried on the well site when no environmental harm is expected.

Oregon - When no longer needed, fluids in pits are to be disposed of in a manner approved by the Department of Environmental Quality. The sumps are then filled, covered and the site restored to a near natural state.

Pennsylvania - As of 1987, drilling pits have been virtually unregulated. Pits typically are unlined and not reclaimed. The State is in the process of developing regulations to control oil and gas operations.

South Dakota - When drilling operations cease, the water in the pit is allowed to evaporate and the mud is allowed to dry. The pit is then covered and the surface restored to its natural condition.

Texas - All storage, disposal and other treatment of oil and gas wastes require a permit. Pit locations are evaluated on a case-by-case basis. A permit to maintain or use any unlined pit, other than an emergency salt water pit, for storage or disposal of oil field brines may only be issued if the State determines that the applicant has conclusively shown that the use of the pit cannot cause pollution of surrounding productive land, or surface or subsurface waters. A permit to use a pit will outline the conditions under which the pit may be operated, including (dewatering, backfilling and compacting). Notice of the permit application is given to affected parties, and a public hearing may be held upon request of any affected party.

The State requires all pits to be dewatered, backfilled and compacted according to specific schedules depending on the type of pit and when applicable, the chloride concentration. The authorization for disposal of drilling fluids is limited to non-oil-based drilling fluids. Oil based drilling fluids (except for the cuttings) must be removed and disposed of in an authorized manner prior to pit closure. Where the water-based drilling fluids have a chloride concentration in excess of 3 000 mg/L, but the wastes have been dewatered, burial is authorized.

Utah - Salt water and oil-field wastes associated with the drilling process may be disposed of by evaporation if impounded in earthen pits underlain by soil of low permeability, hardpan or lined in a manner acceptable to the State. Final pit closure requirements are vague and not detailed.

Virginia - Regulations require pits to be lined with a plastic liner and to be constructed to preclude pollution of State waters. The fluid produced during drilling has a low salt content. Pits associated with drilling must be reclaimed within one year after drilling ceases. No other requirements are outlined.

West Virginia - Temporary storage pits used to contain wastewaters must be constructed to prevent seepage and overflow onto surrounding areas. These pits must be lined if the existing soil does not prevent seepage. After liquid disposal, the drill cuttings may be buried on-site.

Wyoming - Earthen pits are required to be constructed to "prevent pollution of streams, underground water, or unreasonable damage to the surface of leased premises or other lands". The rules do not require pit or pond liners, leak detection systems, or other modifications to an earthern pit, except where "potential for communication between pit contents and surface water or shallow groundwater is high". Each pit application is reviewed before approval, taking into consideration a wide variety of factors, including soil type and the quality of the contained water, particularly the total dissolved solids content.

After evaporation, or removal of liquid material from the pit, drill cuttings are buried on-site and land rehabilitation is completed with agreement from the landowners. Bonds which guarantee pit reclamation are not released until the State has inspected and approved the reclaimed pit.

3.3.2 Federal Regulations

Exploration, development, drilling and production of onshore oil and gas on Federal and Indian lands are regulated separately from non-Federal lands.

The Bureau of Land Management considers reserve pits, and some other types of pits, as temporary. The document entitled "Notice to Leases 2B" includes the following provisions for "Temporary Use of Pits":

1. Unlined surface pits may be used for handling or storage of fluids used in drilling, redrilling, reworking, deepening, or plugging of a well provided that such facilities are promptly and properly emptied and restored upon completion of the operations.
2. Mud or other fluids contained in such pits shall not be disposed of by cutting the pit walls without the prior authorization of the District Engineer.
3. Until finally restored, unattended pits must be fenced to prevent access by livestock and wildlife.
4. Unless otherwise specified by the District Engineer, unlined pits may be used for well evaluation purposes for a period of 30 days.

Land spreading of drilling and rework wastes by breaching pit walls is allowed when approved by the District Engineer.

The foregoing information shows a great variation in requirements between jurisdictions. The most restrictive and/or comprehensive regulations or guideline appear to be those of the states of Alaska, Arkansas, Kansas, Kentucky, Louisiana, Michigan, North Dakota, Oklahoma, and Texas. The regulations for these jurisdictions should be obtained and reviewed in detail when guidelines and regulations are revised in Alberta.

3.4 Industry Guidelines

3.4.1 Canadian Petroleum Association

A set of waste disposal guidelines for the petroleum industry (Canadian Petroleum Association 1988) provides some direction for the disposal of drilling waste solids.

The preferred disposal method for freshwater mud solids is described as burial or surface spreading depending on the circumstances at the time. The preferred disposal method for solids from salt-based muds is the same manner as that for the freshwater muds but may require review by the appropriate regulatory agency. The guidelines suggest that the salt levels in solids may need to be reduced by washing prior to disposal.

The preferred disposal system for oil-based mud solids is to spread on the lease and allow to dry. After an initial drying period, the solids are then worked into the disturbed surface soil layer and returned to the sump.

The acceptability of this method is questionable, as the fate of the buried organic components of invert muds is of concern (pers. comm., H. Lillo, Manager Environment Protection, ERCB 1990) and depends upon the degree of biodegradation during the surface incorporation period.

3.4.2 American Petroleum Institute

A presentation by Springer (1989) summarized guidelines for management of onshore drilling wastes prepared by the American Petroleum Institute. These guidelines are not a substitute for regulatory requirements. Their recommendations with respect to management of freshwater pit solids, salt-based solids and oil-based solids are given below.

Freshwater pit solids should be land disposed on-site. Alternatively, they may be hauled to off-site disposal facilities.

Residual pit solids containing salts with an exchangeable sodium percentage exceeding 15 may be buried or landspread on-site if done in a manner to protect arable soil and to prevent leaching into usable groundwater. Salty pit solids may be removed from the site and taken to permitted off-site disposal facilities. Encapsulation may also be practical. Alternatively, salts may be removed by washing, the salty washwater deep well injected, and the low salt solids managed like freshwater solids.

Oil-based pit wastes that cannot practically be reclaimed or reused should be taken to off-site disposal facilities capable of handling oily wastes or buried or landspread on-site if the waste soil mixture can be reduced to less than one percent oil and grease content by weight. It may be possible to reduce the oil content of some muds by washing mud solids to reach this criterion. Burial of solids with oil and grease content in excess of one percent may be feasible when approved solidification techniques are used.

After pit wastes are managed, the pit site should be compacted, contoured, and vegetated where necessary to provide ground support stability and prevent erosion of the well location. Records should be kept of pit locations.

3.4.3 Concawe

A review of the 1989 catalogue of CONCAWE reports (the oil companies' European organization for environmental and health protection) did not refer to any reports on oil well drilling wastes.

4. BENEFITS AND DRAWBACKS OF BURIAL

The burial of wastes in unlined pits can adversely affect surface water, groundwater, soils and vegetation. The following discussion describes the potential for such contamination with respect to the burial of drilling waste solids. Although surface and groundwater are treated separately throughout the following discussion, it is realized that the two are often interchangeable. The section concludes with a comparison of the burial method with other disposal options.

4.1 Water

Leskiw et al. (1987) identified four possible causes of surface water contamination. The following two would apply directly to burial practices:

1. leaching from on- or off-site disposal areas; and
2. discharge of contaminated groundwater to surface water sources.

Drilling waste solids do not present as high a risk to surface water systems as do the liquid components of a sump because overland flow is the primary mechanism by which drilling wastes will reach a lake or stream (Leskiw et al. 1987). In contrast, land spreading distributes the waste on the surface and has a potential for surface water contamination, if the site has a high run-off potential.

The primary concern of the burial disposal method is the possibility of groundwater contamination as a result of waste component migration or leaching. In Alberta, nearly 40% of the population is dependant on groundwater as the sole water supply (Ceroici 1986). Groundwater is not only a source of potable water, but also serves industrial purposes.

Glass column analyses of waste drilling fluid showed hydraulic conductivity to decrease rapidly to values of 10^{-8} cm/s as a result of settling on the pit walls and bottom (Deeley 1989). Similar behaviour in a disposal pit would result in a low permeability filter cake. Field studies and groundwater modelling have shown leachate concentrations to decrease with rapidly increasing distance from the source (American Petroleum Institute 1987; Henderson 1982; Kemblowski and Deeley 1987).

Murphy et al. (1986) reported degradation of shallow groundwater from leachate generated from buried salt-based drilling waste in North Dakota. Two sites located within glacial sediments displayed different results. At one site, hydraulic conductivity was inherently low and leachate did not move far beyond the pit. The second pit, which was located in water saturated glacial fluvial sand and gravel, had leachate migrating beyond the 91.4 m (300 ft) radius of instrumentation.

Currently, burial in Alberta is only practised with freshwater gel and salt-based muds. Burial of invert muds is no longer acceptable due to experience of hydrocarbon migration from the pits (pers. comm. H. Lillo, 1990). O'Leary et al. (1989) have prepared a detailed report of a groundwater monitoring program at the Peace River Expansion Project (Shell Canada Limited). The mix, bury, and cover method (dilution - burial) was selected as the disposal method that would minimize environmental impacts. A volume of 22 000 m^3 of KCl drilling waste solids were buried in an area underlain by up to 5 m of weathered clay till, over at least 11 metres of relatively homogeneous, very stiff, unweathered clay till. The hydraulic conductivity of this native material ranged from 10^{-8} m/s to 10^{-11} m/s. The disposal procedure involved draining the KCl drilling waste solids of free water, spreading the remaining solids on-lease to dry and then mixing with the excavated clay till. This waste/till mixture was backfilled into the pit, compacted into 3 metre thick layers and capped with a compacted 2 metre thick clay cap to reduce infiltration. The reclamation effort also included contouring the 8 ha disposal site to enhance surface runoff and revegetation of the area for erosion control. Three years after drilling wastes were first brought to the site, and 1.5 years after completion of disposal and restoration, groundwater monitoring has shown soluble constituents from the waste/till mixture have been contained within the disposal site.

It should be emphasized that site was classified as a class II industrial landfill approved by Alberta Environment, and was properly designed, operated and closed. However, three years cannot be considered as long term.

4.2 Soil - Plant Relationships

The effect of burial of drilling solid wastes on soil and plant relationships is not fully understood. However, a number of potential problems are possible.

One concern is the potential impact of the buried material on the soil replaced on the surface. In a broad sense, the chemical impact is restricted to the effects of soluble salts, heavy metals and hydrocarbons.

From a physical stand-point, concerns of changes in soil density and structure as a result of soil storage and replacement are of prime importance. These changes are not exclusive to reclamation of the sumps but apply to the entire lease area. As well, the reduction of internal drainage due to a layer of dispersed bentonite has not been addressed.

A third aspect involves the effect of stockpiling topsoil on the mineralization of organic matters and the loss of available plant nutrients.

A study conducted by the ERCB (1985) examined the impact of drilling waste on plant growth. This study appears to be restricted to the on-site disposal of drilling fluids and the impact of surface disturbance as a result of drilling preparation and reclamation. The effect of buried drilling solids is not specifically addressed but it appears to be incorporated into the overall reclamation assessment. A total of 194 drilling sites were assessed in 1982 and 1983. The results of this study indicate that reclamation of the sites was generally successful. The majority of unsatisfactory reclamation sites were characterized by a lack of or inadequately replaced topsoil. Minor concerns with respect to spills, subsidence, compaction and the presence of solonetzic soil, or overgrazing were reported in only a few cases. This study was conducted by visual observation and limited chemical and physical analysis.

4.2.1 Chemical Implications

Generally, the buried drilling waste solids are covered with a 1 metre layer of native stockpiled soil. There is a concern with respect to soil degradation as a result of shallow burial of bentonitic muds in the pits or over the drill site (pers. comm. S. Tracy, Manager Land Conservation and

Reclamation Council, Alberta Environment 1990). As plant roots usually do not penetrate beyond 1 metre of soil, the chance of the roots encountering salts, heavy metals and hydrocarbon is remote.

One concern is the possibility of the upward migration of soluble salts into the active root zone. Extensive experience in dryland salinity work in Alberta has shown that salts will migrate into the root zone if a saline groundwater table is within approximately 2 metres of the soil surface (pers. comm. H. Vander Pluym, Head, Soil Conservation Section, Conservation and Development Branch, Irrigation and Resources Management Division, Alberta Agriculture, 1990). Soil salinization is most likely when the muds are salt water-based and when the water table is high. This high water table occurs as the result of an impermeable layer of soil below the land surface. The rate of upward movement would depend on moisture conditions in the area.

Heavy metals may be deleterious for two reasons: 1) they are phytotoxic and available to plants, and 2) they can be present in plant tissue at levels that exceed the levels chronically tolerated by animals.

From a phytotoxic standpoint, the metals of concern include: arsenic, boron, copper, vanadium, nickel and zinc. From a dietary standpoint, the metals of concern include: cadmium, cobalt, copper, molybdenun, nickel, lead, selenium, zinc and possibly manganese. However, as stated earlier, the uptake of these metals would be restricted if a layer of 1 m of soil is placed over the solids. In addition, the study of a number of sumps in Alberta by Macyk et al. (1990) showed that the total metal concentration of the solids were within the range found in uncontaminated soils.

The concentration of petroleum hydrocarbons in drilling wastes is variable, ranging from zero to a high of approximately 8% for invert muds. Controversy exists on the extent of hydrocarbon toxicity to plants. Phytotoxicity limits for hydrocarbons range from 0.5% to 1% for fresh oil to 2% for weathered oil in soils 30 cm from the surface. There are no criteria for the impact of high oil content soils occurring at 1 m depths. It is assumed that oil contents below the root depth of 1 m would have little effect on plant growth.

Based on the above discussion, it is assumed that the most significant chemical problem for plant growth is the possible upward migration of soluble salts from the buried solids where the water table is within 2 m of the surface. Upward migration of heavy metals and hydrocarbons in high water table areas is not considered a problem because these elements and compounds are retained within the soil system.

4.2.2 Physical Implications

The physical implications of soil excavation and replacement are important when considering reclamation of the disturbed sites. Most important is the effect of soil compaction and how it influences permeability, aeration, moisture storage, root penetration, seedbed preparation, soil strength, decreased porosity, increased runoff and trafficability. The impact of excavation, stockpiling and replacement on the physical properties of subsoils and topsoils has only recently received much attention (Akram and Kemper 1979; Naeth 1985).

Crabtree (1987) reported on specific problems related to the reclamation of drilling pits in Michigan. The solids left after fluid removal often have a "toothpaste-like" consistency. This has presented problems for the landowner, particularly in areas of low permeability soils and with lined pits. Specific problems include reduced load bearing capacity of the ground over the pit and the formation of wet spots over the pits where internal drainage has been reduced. In response to these physical problems, some operators of sump pits have developed processes designed to stabilize the drilling muds. These processes involve the addition of cement kiln dust, cement, aggregate, and other stabilizing materials to the drilling muds and cuttings remaining in the pits after excess fluids have been removed.

The presence of a dispersed layer of bentonite materials will reduce the internal drainage and affect the water table level at the site. This aspect has not been investigated in Alberta.

Leskiw et al. (1987) consider that changes in physical characteristics, such as soil structure and bulk density within the root zone above the buried material, are the main factors affecting plant growth when drilling wastes are buried or contained in deep trenches. These changes are the result of disturbance and compaction of the materials by heavy equipment during material replacement. This deleterious effect would be magnified when the soils are fine textured.

Subsidence is probably the most visible result of burial as it results in rough topography and possibly ponding of water in the depressions. Remediation of the problem is relatively simple but inconvenient.

In conclusion it appears that the placement, levelling and the associated effects on soil density plays a significant role in reduced plant growth. Although the bulk density is reduced by wetting and drying, freezing and thawing and eventual root penetration by plants, the effect may last for many years. The suggestion that the mud pits be capped with compacted soil in order to reduce infiltration is in conflict with the concept of optimum plant growth in these areas. Subsidence problems require returning to the site for remediation.

4.2.3 Plant Nutrient Implications

Topsoil used to cover the reclaimed sump and subsoil used to mix with sump contents and/or cover sump contents are usually stockpiled when the sump is initially excavated. The literature is inconclusive regarding the effect of stockpiling topsoil on plant nutrient status. Topsoil rich in organic matter is important in providing and storing nutrients. These nutrients are slowly released as the organically bound nutrients (especially nitrogen) are mineralized to plant available forms. This mineralization process has generally been considered to be enhanced by cultivation. In North Dakota, available nitrogen was found to be lower for stockpiled soils than for undisturbed soils regardless of organic matter content (Wollenhaupt and Richardson 1983). These results were not duplicated by Fujikawa (pers. comm. Soil Protection Branch, Alberta Environment, 1990) at an experiment at Bow City, Alberta. He found more nitrate-nitrogen in stockpiled soils than in cultivated and undisturbed grassland soils.

This subject is not addressed in further detail in this study as RRTAC is presently investigating this issue (Thurber Environmental Consultants et al. 1990). This subject is not restricted to buried solids but applies to the entire lease area.

4.3 Economics

In Alberta, the most common disposal practices are burial and land application of the drilling waste solids. Table 3 lists the average costs as derived from personal communication with industry staff. Burial costs can be $6.00/bbl, and greater, depending on the type of mud waste handled, treatment requirements and whether burial is on or off lease (pers. comm. F. Cartwright, Senior Operations Foreman, Drilling Division, Shell Canada, 1990).

In the United States, dilution-burial and land spreading are the most economical methods followed by solidification/burial. The relative costs are listed in Table 4. The least cost-effective alternative is off-site disposal to a commercial facility. In this case the operator of the sump pit must pay to remove the wastes from the pit, transport the wastes to the disposal site, and pay the disposal facility operator.

4.4 Comparison of Options

Drilling solids, especially the salt-based and invert muds have no known beneficial value, and therefore should be disposed of in the least harmful manner. At the present time the best disposal method appears to be based on theory and philosophy rather than on actual data. The impact of the different methods of disposal (burial, land spreading, landfilling, incineration, solidification/fixation, road application and disposal in saline slough) on the surrounding environment has not been adequately documented and/or reported.

Table 3. Average Disposal Costs in Alberta

Disposal Method	Waste Component	Cost
Burial	Solids	$1.50 to $3.50/bbl*
Land Spreading Only	Solids	$1.00 to $3.00/bbl
Land Spreading Only	Liquid	$0.50 to $1.50/bbl
Dewatering	Sump Contents	$2.00/bbl

* bbl = petroleum barrel; 1 bbl = 0.1589 m^3

Table 4. Disposal Costs in the United States

Disposal Method	Cost (Hanson et al. 1986)
Reserve pit solidification	$8.00(US)/bbl
Landfarming (oil and water-based fluids)	$1.50 to $10.00(US)/bbl
Dewatering	$2.00 to $3.00(US)/bbl
Solidification	Cost (Calloway 1986)
In-situ injection and mixing	$12.00 to $13.00(US)/bbl
Volume reduction/solidification	$6.00 to $8.00(US)/bbl
High solids solidification	$10.00 to $35.00(US)/bbl

Determination of the least harmful method of drilling waste solids disposal is complicated by the organic component (hydrocarbons) and the inorganic components of Na, K and Cl. Hydrocarbon contamination of surface and groundwater along with leaching of salts to the surrounding environment are major concerns.

4.4.1 Burial

Burial practices are the most economical alternative for the disposal of drilling waste solids (Section 4.3) when the additional cost of backfilling the pit after the solids have been removed for landspreading is considered.

The most significant negative impact of burial is the fate of the organic component of the solids, particularly the possibility of hydrocarbon contamination of the surrounding groundwater. The main concern is that buried hydrocarbons are not rapidly biodegraded by soil micro-organisms and will persist in the soil for long periods of time (pers. comm. H. Lillo, Manager, Environment Protection Dept. ERCB, 1990).

Another concern is that the burial of the solids, particularly those associated with salt-based muds, creates a concentrated source of soluble salts that are subject to leaching and groundwater contamination. In situations where the water table is within 2 metres of the surface, the soluble salts may move upward through capillary action resulting in soil salinity at the burial site.

The burial methods requiring a compacted covering layer of soil may result in reduced vegetative production for a number of years (Section 4.2.2).

4.4.2 Land Spreading

Compared to burial, land spreading provides an environment more favourable to the oxidation and microbial degradation of hydrocarbons. The method may, however, require several years for complete mineralization. Land spreading along with burial are two of the most cost-effective methods. However, saline materials spread over large areas have great potential for negative impacts on soil and water if application rates are excessive.

4.4.3 Landfilling

In Alberta, the number of commercial landfills are limited; only three industrial landfills currently exist. This disposal method can be least cost-effective when the need to remove the waste from the sumps, transport the waste to the off-site landfill and finally, the disposal of the waste at the landfill is considered. Strict limits on the waste contents imposed by regulations may make this option inapplicable.

However, a secure landfill presents one of the most environmentally safe methods with respect to long term immobilization of the soluble salt component of drilling waste solids. Based on available analytical data, the solid fraction resulting from dewatered drilling muds would not be considered a hazardous waste (pers. comm. A.L. Fernandes, Industrial Waste Branch, Wastes and Chemicals Division, Alberta Environment, 1991). As such, on-site or off-site disposal in properly designed landfills or pits is recommended. An adequate design, using sound principles could also apply to common burial practices. These principles include controlled dewatering, favourable hydrogeology, adequate cover and finally, a layer of suitable topsoil for revegetation. The other equally expensive approach is soil washing followed by deep well injection of the wash water.

4.4.4 Incineration

Incineration results in rapid mineralization, but is presently viewed as prohibitive because of cost and the technology. Gillam et al. (1989) viewed incineration of oil-based mud cuttings to create the least environmental impact in the Canadian arctic. This disposal method still results in salt-containing residues which must be dealt with further.

4.4.5 Solidification/Fixation

Chemical and physical alteration of the drilling waste to maximize containment would appear to be more appropriate in the short term than simply mixing with excavated materials to stabilize the chemicals. Costs would be increased with this method and since the contaminants are left on-site, long term liability must be considered.

4.4.6 Road Application

Incorporation of salt or invert-based drilling waste into road beds can present potential leaching problems when rainfall events create surface infiltration and seepage. Contamination could be more widespread than for a waste contained within a sump.

4.4.7 Alkali Slough

Disposal to saline sloughs, as allowed in Saskatchewan, is probably the least harmful disposal method with respect to soluble salts as these sloughs are very saline by nature. The alkali slough method assumes availability of an alkali slough whether on-site or off-site; in the latter case transportation costs would be incurred.

5. DESCRIPTION OF BURIAL PRACTICES IN ALBERTA

This section discusses the types of drilling solids that are buried in Alberta, the types of sumps used, the use of liners, alterations of burial methods in cold climates, monitoring, and successes and failures of burial methods.

5.1 Type, Location and Duration of Materials Buried

In Alberta, the three drilling mud types used can be geographically designated as (pers. comm. U. Ziedler, President, Mission Mud Control, 1988, Ltd., 1990):

1. Invert and KCl based muds: foothills of Alberta from Waterton to west of Grande Prairie.
2. Salt-based muds: eastern part of province in the red earth/evaporite region and along the Alberta-Saskatchewan border in the Frog Lake area.
3. Freshwater-gel muds: throughout the province; sometimes used only for drilling the upper portion of the borehole.

Currently, the burial of freshwater-gel and salt-based drilling solids is approved by the ERCB while the burial of invert muds is not allowed (pers. comm. H. Lillo, Manager, Environment Protection Dept., ERCB, 1990). On the other hand, the Public Lands Division, Alberta Forestry, Lands and Wildlife does not advocate burial of salt-based solids on public lands (review comments by W.S. Tedder, Public Lands Division, Alberta Forestry, Lands and Wildlife, 1990). Burial of invert wastes is not approved by the ERCB due to migration and lack of aerobic degradation of the organics. The mix, bury and cover method is the most common burial method in Alberta. Sump contents are stabilized and diluted through mixing either on the surface, or directly in the pit, with the native excavated subsoil material. A low permeability cap and a topsoil layer are then placed over the sump.

Sump wastes have been buried since the early years of oil and gas drilling. Some sumps are at least 52 years old (i.e., since the ERCB was formed). Although there are no time limitations placed on the closure of pits after drilling operations cease, it is good practice to close the pit within one year of its construction. In the United States, pit storage time ranges from a maximum of 13 months for shallow wells to as long as 30 months for deep wells with an average storage time between 8 to 14 months (Freeman and Deuel 1986).

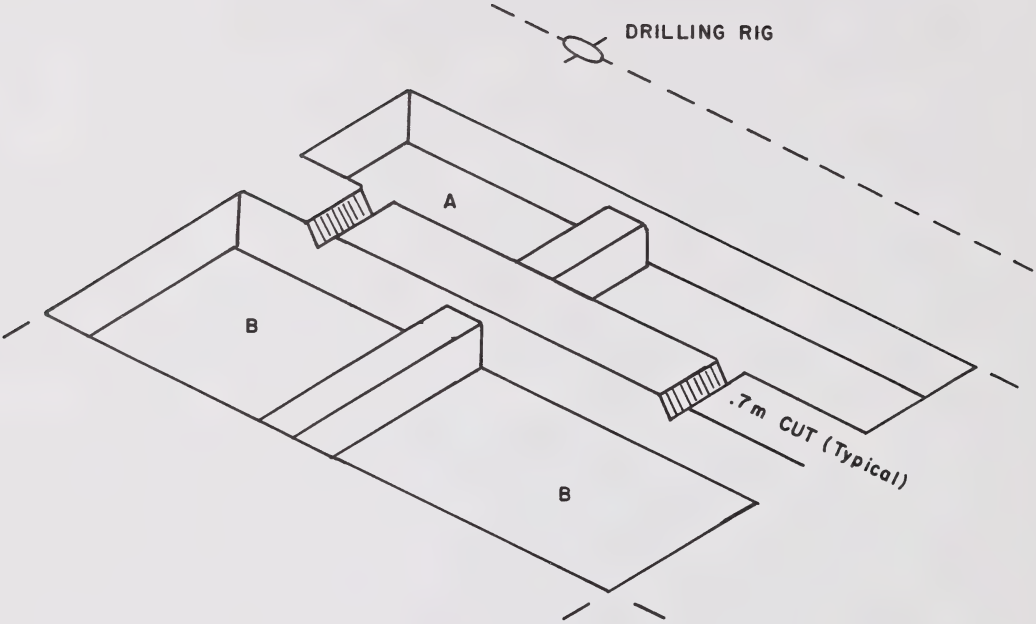
5.2 Drilling Sump Types

A typical sump is rectangular in shape with a flat bottom at a depth of three to four metres for shallow wells or six metres for deep wells. Its freeboard at closure would be a maximum of one metre with a berm around the sump's perimeter. The size of the sump itself would depend on the depth of well drilled and on the amount of land available on the lease for sump construction.

Variations of the typical sump design include multiple sumps in series and/or with a sloped bottom. The sumps illustrated in Figures 1 to 6 were supplied by the courtesy of Petro Canada. The multiple sump design shown in Figures 1 and 2 allows for successive clarification of the liquid through natural settling. In Figure 3, sloped bottoms are incorporated to inhibit solids flow. A sloped bottom sump was also used in the Peace River Expansion Project by Shell Canada Limited to increase free water drainage from the solids and permit easier dumping and removal of the solids (Davies and Wensley 1987). For drilling operations with two stage drilling mud systems, an isolation sump such as that shown in Figure 4, can be utilized. In the case of a remote sump, Figure 5 shows a design with four reversed-slope subsections for application in single or multi-well projects. Figure 6 is a sump designed like a 'paint-tray' which removes and collects oil from solids for possible reuse. This type of sump is applicable to all well depths utilizing oil additives.

FIGURE 1 A SERIES DRILLING SUMP

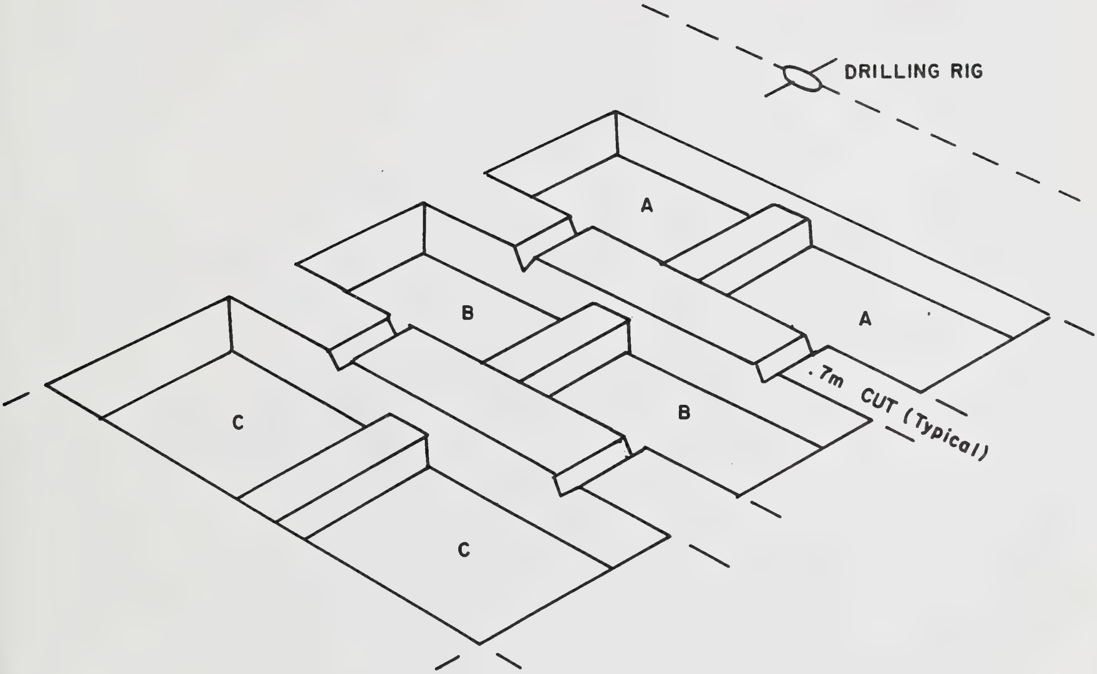
(Courtesy of Petro- Canada)



CLASSIFICATION:	- A Series.
APPLICATION:	- 0 to 500 metre well depths. - On-site control of a singular mud system
DESCRIPTION:	- Two (2) parallel, flat bottomed pits with dividers across width.
FEATURES:	- Pit A allows for minimum freshwater precharge and immediate fluid return to drill out surface portion of well--contains heavier solids. - Pit B serves as overflow and containment of transition or gel-like muds through duration of drilling operations.
VOLUME:	- Total volume (m^3) of all pits equals well depth in metres.

FIGURE 2 B SERIES DRILLING SUMP

(Courtesy of Petro- Canada)



LASSIFICATION: - B Series.

PPLICATION: - 500 to 1000 metre well depths.

- On-site control of a singular mud system

ESCRIPTION: - Three (3) parallel, flat bottomed pits with dividers across width.

EATURES: - Pit A allows for minimum freshwater precharge and immediate fluid return during surface portion of well--contains heavier solids.

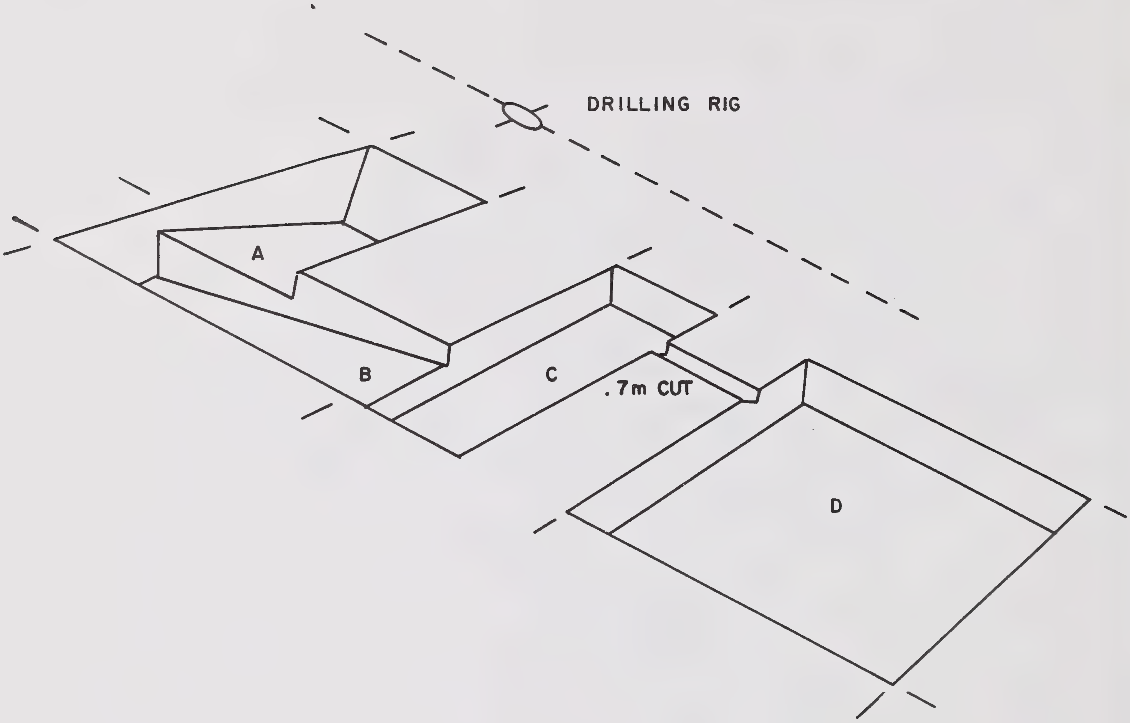
- Pit B duplicates function of A for the intermediate section of the well and contains transition or gel-like muds dispalced from A

- Pit C primarily designed as overflow for fluid displaced through A and B, but in excess of rig demand.

OLUME: - Total volume (m^3) of all pits equals well depth in metres.

FIGURE 3 C SERIES DRILLING SUMP

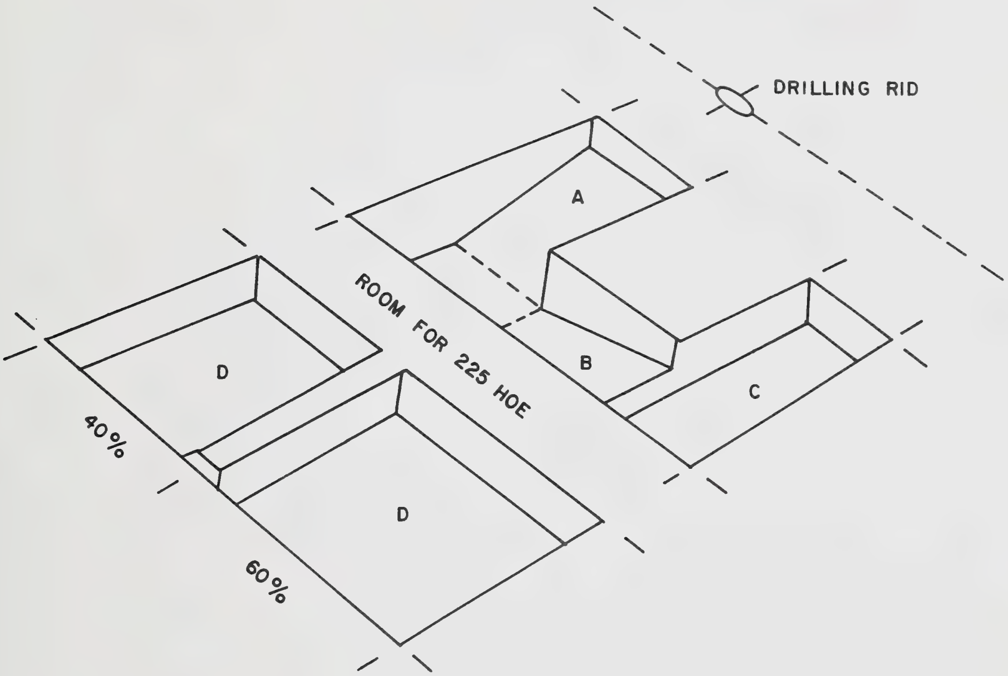
(Courtesy of Petro- Canada)



CLASSIFICATION:	-	C Series.
APPLICATION:	-	1000 to 4750 metre well depths.
	-	On-site control of a singular mud system
FEATURES:	-	Primary feature is the reversed-slope in each of the A, B, and C pits--inhibiting solids flow and enhancing flocculation of reusable fluids.
	-	Minimizes volume of freshwater precharge in larger volume sumps--only necessary to fill and maintain volume in Pit C until fluids accumulating from shale shaker, etc., (Pit A) are displaced by solids volume into C-- the sump should then be self-maintaining to completion of well.
	-	In latter stages of drilling operations, the fluid volume in excess of rig demand is contained in Pit D.
VOLUME:	-	Total volume (m^3) of all pits equals well depth in metres.

FIGURE 4 ISOLATION SUMP

(Courtesy of Petro- Canada)



CLASSIFICATION: - Isolation Sump.

APPLICATION: - On-site control of two stage (primary and secondary drilling mud systems).

DESCRIPTION: - Basically a "C" Series sump with two alterations--1) The slope in Pit A is toward Pit B 2) The overflow, Pit D is moved parallel to Pit B rather than C.

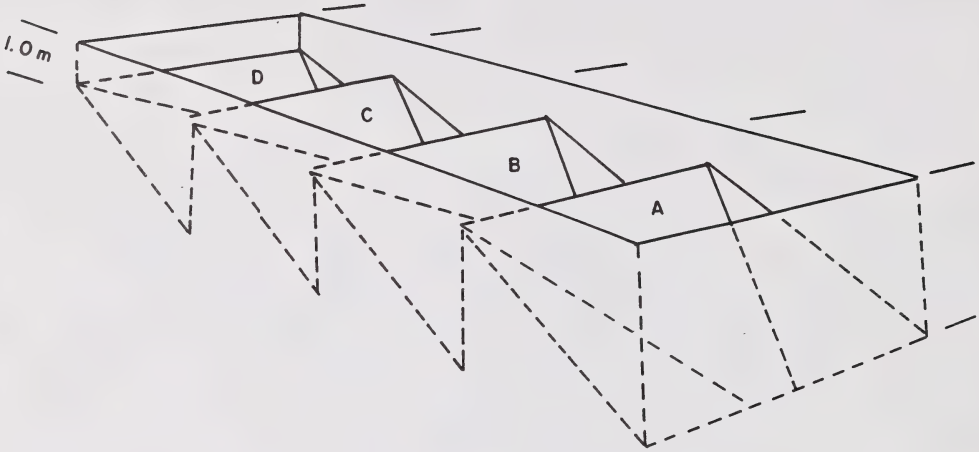
FEATURES: - Pit A, B and C volume equals well depth for primary mud systems.

- Two (2) parallel, flat bottomed pits with dividers across width.
- As drilling operations approach primary depth, total contens of A, B and C are transferred to D, utilizing pumps (and/or backhoe for solids).
- Secondary mud systems may then be isolated in Pits A, B and C.

VOLUME: - Total volume (m^3) of all Pits A, B and C equals well depth in metres for the primary mud system only.

FIGURE 5 REMOTE SUMP

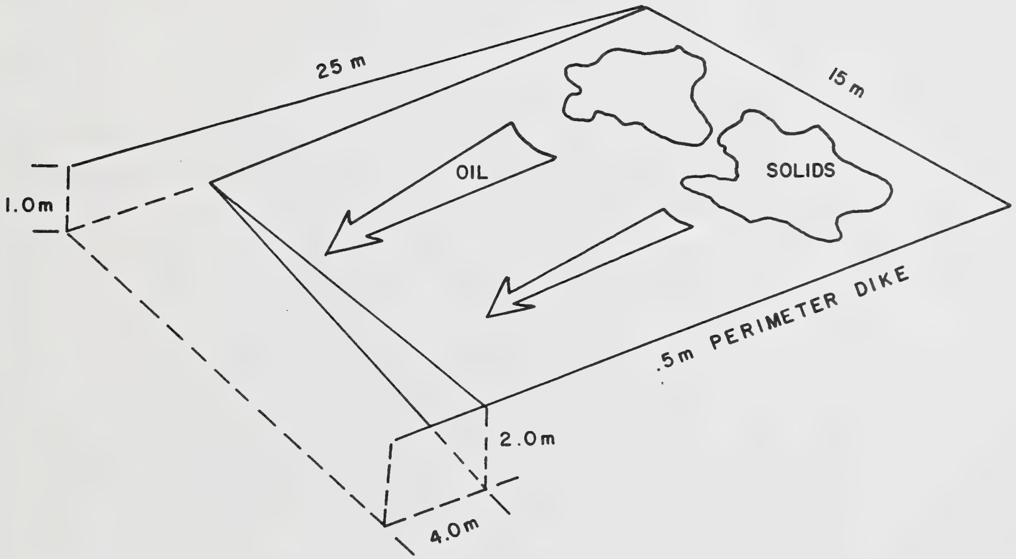
(Courtesy of Petro- Canada)



CLASSIFICATION:	- Remote Sump
APPLICATION:	- All wells--including fluid management on multi-well projects.
DESCRIPTION:	- Long, narrow pit with four (4) equal sections for off-site control of a singular mud system and /or isolation of diverse systems by building multiple, 4 unit pits of smaller dimensions.
FEATURES:	- Primary feature is the reversed-slope in each of the four sections--inhibiting solids flow and enhancing flocculation of reusable fluids.
	- Proper use requires that waste be introduced at the deep end of Pit A and that vehicular access be maintained through Pit D--permitting recovery of reusable fluid as flocculation takes place.
VOLUME:	- 0 to 2200 metre well depth--requires (4 unit) configuration.
	- 2200 to 4750 metre well depth--requires development of two (4 unit) pits--each equal to 50% of total well depth.
	- Total volume of 4 unit (or pits in wells in excess of 2200 metres) equals total well depth in metres.

FIGURE 6 INVERT CONTROL SUMP

(Courtesy of Petro- Canada)



CLASSIFICATION:	-	Invert Control.
APPLICATION:	-	All wells depths utilizing oil additives.
	-	On-site/off-site containment of oil contaiminated solids.
DESCRIPTION:	-	"paint tray" - broad expanse of shallow sloped area for solids)(diked against surface shallow runoff) culminating in fluid.
FEATURES:	-	Catch pit for oil.
	-	Design allows oil to seep from solids and be collected for reuse.
VOLUME:	-	NO APPLICABLE CALCULATION.

5.3 Containment Methods

Sump liners for containment of drilling waste solids are made of either synthetic or native materials. In Alberta, synthetic liners are not commonly used for permanent burial of drilling wastes. Synthetic liners are sometimes used temporarily to contain sunken tanks whose waste contents eventually go to a remote sump. A major concern with synthetic liners is the possibility of leakage arising from punctures and tears incurred during installation and closure operations.

A more common construction material for liners is glacial till found throughout most of Alberta. Its high clay content provides low hydraulic conductivity and low permeability properties which help minimize movement of waste constituents out of the sump. Low moisture content would, however, cause fissures or macropores. A study by Pauls et al. (1988) found an optimum combination of 75% maximum sand content which limit shrinkage with compaction giving slightly above optimum water content to keep the permeability below 1×10^{-7}cm/s. This same study determined that the governing mechanism of contaminant transport was advective flow, rather than diffusion. In clay materials, advection is usually 3×10^{-8}cm/s or greater.

Since salt-based waste sumps exist in Alberta, it is important to recognize that a hypersaline environment can alter the behaviour of clay liners. Smectite clays, such as montmorillonite, exhibit increased permeability to saline and organic solutions (Pauls et al. 1988). Similar results were observed in montmorillonite-rich soils exposed to a 30% NaCl brine environment (Ridley et al. 1984). Soils rich in illite and kaolinite exhibited virtually no variations to solution composition.

5.4 Cold Climate Burial

Scattered permafrost occurs in northern Alberta. Between this perennially frozen earth material and the surface, an active layer of soil or rock exists which thaws in the summer and freezes in the winter. Given the seasonal change, both the location of the sump and the timing of construction and restoration are important considerations.

Some problems encountered in the burial of water-based drilling waste in this cold environment are (Gillam et al. 1989):

1. mixing of wastes and infill material (volcano effect) arising from the weight of the overburden collapsing the surface of the sump; and
2. sump subsidence and collapse, which results either from incorporation of snow and ice with the infill, underground erosion, or both.

To prevent these problems, it is recommended that restoration be done in late winter. A domed gravel cap should cover the sump and snow or ice should be reduced and/or removed from the infill material. Furthermore, sump activities from construction to restoration should take place during the same winter. This practice minimizes any thawing of the permafrost and ensures in-situ freezing of the waste material.

With salt-based drilling waste, the sump may not remain sufficiently frozen to prevent contamination of the surrounding environment. This may be due to freezing point depression or the existence of discontinuous permafrost. To address this problem, the following recommendations were made by Nenniger (1987):

1. dilute the saline drilling waste fluid as much as practical with freshwater to minimize the freezing point depression;
2. place the fluid below the active surface layer;
3. provide additional barriers to thawing by sealing the saline drilling waste fluid with a freshwater layer before the sump is back filled;
4. use of clay liners is not recommended since their effectiveness is greatly reduced by the salts; and
5. use of synthetic liners is not recommended since they may crack and split at the extremely cold temperatures.

5.5 Monitoring

To date, there are no regulations directly enforcing short or long term monitoring of burial sites. Corrective measures are acted upon only after a problem of contamination is identified. However, very few contamination or restoration problems have been observed, especially with the burial of freshwater-gel based waste solids. Any subsidence at the sump surface is usually corrected by adding more fill and topsoil material. This is repeated if necessary until the problem is eliminated.

One documented case of monitoring is of the Peace River Expansion Project by Shell Canada Limited. One and a half years after the restoration of the disposal site, analysis of groundwater quality surrounding the site indicated minimal environmental impact associated with the burial of KCl waste solids (O'Leary et al. 1989). Due to the low moisture content of the buried material and the hydrogeological characteristics of the site, minimal environmental impact is expected.

5.6 Successes and Failures

Burial has been one alternative for the disposal of certain drilling waste solids. Currently, the burial method of mix, bury and cover is widely utilized in Alberta. This method has been demonstrated to be a very effective means of disposal when the sump is correctly sited. This requires the presence of low permeability clay till and a low water table. Before, during and after the drilling operation, it is best that the sump not be viewed as a garbage pit where items such as scrap iron, drums, cans, casing protection material, engine oil, and rig wastes are directed. The lack of waste segregation can only complicate the cleanup procedure. During sump closure, adequate mixing and drying prior to back filling and proper covering will lead to a more successful burial.

As stated earlier, invert mud is no longer buried. A documented occurrence of buried invert mud migrating down a hillside and into a creek has clearly shown the inappropriateness of burying invert muds (pers. comm.

H. Lillo, Manager, Environment Protection Dept., ERCB, 1990). Land spreading and land treatment is the more acceptable option for this mud when dealing with small amounts of invert drilling solids. Large amounts of mud may have a significant environmental impact.

Preplanning and awareness training of all drilling personnel have been stressed strongly by both industry staff and government agencies. This preventative approach minimizes both clean-up complications and associated environmental impact. According to Lal and Thurber (1989), three basic requirements make up a good waste management system:

1. minimize the quantity of wastes during the operation;
2. control the quality to keep wastes non-hazardous; and,
3. process/dispose of wastes in an environmentally-safe and cost-effective manner satisfying the regulations.

Minimization of wastes should address all wastes generated from well site activities and not only drilling fluids and drill cuttings. Identification and isolation of wastes is crucial.

In summary, burial practices are employed for the disposal of freshwater-gel and salt-based muds. A number of sump configurations are possible. Synthetic liners are used only in special circumstances. The most commonly used liner is compacted till. Some of the problems encountered in the burial of wastes in cold climates can be avoided by conducting the restoration work in the late winter. The mix, bury and cover method of burial is widely used in Alberta and has been considered very effective when conducted properly.

6. EXPERIENCE AND TRENDS ELSEWHERE

A review of literature on disposal practices employed in Europe is summarized in the following section. A closed cycle system is also briefly described.

6.1 European Experience

The Netherlands experience studied by Veltkamp and Jurg (1989) showed annual generation of 60 000 t of drill cuttings and 300 000 m^3 of liquid waste from onshore drilling activities. Prior to 1970, disposal of waste solids was at public and private dumping sites or as fill material in ditch and canal construction. Since 1970, waste solids are disposed of at regulated landfill sites where leaching to groundwater and soil is minimized as much as possible. The main method in the Netherlands is the disposal of liquid waste in a brackish estuarine area. A more environmentally acceptable liquid waste has been developed from filter-press treatment and chemical treatment. Additionally, permission has also been granted to discharge this effluent into a public biological waste sewage purification plant.

Donally (1989) reported that in Britain most, if not all, of the wastes derived from well sites are disposed of in licenced tips or ground fill sites. These tips are owned and managed by the local authority. Regional water authorities in England and Wales, and the river purification boards in Scotland ensure the total integrity of each site. The Nature Conservancy Council of the United Kingdom has recorded only one problem from land spreading. Due to lack of proper control, valuable heathland was destroyed. Examination of other cases of land spreading has lead the United Kingdom Ministry of Agriculture, Fisheries and Food has resulted in the rejection of this disposal method.

In Italy, work by Dossena et al. (1989) indicated promising results from an effective on-line method for treatment and disposal of drilling wastes. Italian government regulations pertaining specifically to industrial solid wastes and sludges include:

1. authorization for each type of waste disposal must be obtained;
2. waste may not be abandoned and no form of landfarming of sludge is allowed;
3. industrial waste may not be dumped into municipal landfills; and,
4. waste dumped into a landfill must contain no free liquids.

Dumping of industrial wastes is allowed by local authorities if a standard leaching test shows concentrations of heavy metals to be within the limits listed in Table 5.

Many problems were encountered in the traditional method of collecting all wastes in a single, high capacity sump: 1) sufficient surface areas to create large basins are lacking in Italy; 2) area must be restored to its original condition within a reasonably short time; and, 3) efficient handling of the waste, including treatment before disposal is made difficult by its heterogeneous make up.

Realizing the need to operate under the new Italian environmental regulations, the limited availability of suitable landfills and the problems presented in the traditional disposal method, Dossena et al. (1989) developed a waste management system to:

1. confine and separate wastes by types;
2. reduce the quantity of wastes produced;
3. periodically treat and dispose wastes during drilling; and,
4. use purified chemicals to reduce toxicity of the wastes.

Suitable disposal systems were applied to each of the five waste sources: drilling waste liquids, cuttings, slightly polluted water, contingency fluids (oily and acid fluids), and civil wastes.

The filter cakes resulting from chemical treatment and mechanical dewatering of the drilling waste liquids were sent to a suitable disposal site. At the same time, research into using the filter cakes in brick and tile manufacturing was being done. The drill cuttings were consolidated by cementing binders after undergoing mud cleaning and centrifuging. This

Table 5. Leachate Test Limits for Industrial Wastes in Italy. (Dossena et al. 1989)

Parameter	Limit (mg/litre, except pH)
pH	5.5 to 9.5
Suspended solids	80
BOD	40
COD	160
Mineral oils and grease	5
Surfactants	2
Chloride	1 200
Sulphate	1 000
Ammonia	15
Lead	0.2
Mercury	0.005
Copper	0.1
Arsenic	0.5
Selenium	0.03
Cadmium	0.02
Chromium III	2
Chromium VI	0.2
Barium	20

consolidated material was very suitable as infills for worked-out quarries which are common throughout Italy.

The information obtained from the Netherlands, Britain and Italy indicate that the preferred method of drilling solids disposal is in approved landfills. Land spreading of drilling wastes is not allowed in Britain and Italy, and is not practiced in the Netherlands.

6.2 New Technology: Closed Cycle System

A closed cycle system utilizes mechanical solids control equipment (shakers, hydroclones, centrifuges) and mud processors which combine flocculation and centrifuging processes. This minimizes the volume of waste mud and cuttings while maximizing volume of treated liquid and/or weighting materials which are returned to the active mud system (Hanson et al. 1986; Lal and Thurber 1989). Such systems not only present a reduced risk of environmental impact from reduced volume of wastes to be handled, stored and disposed of, but has also been demonstrated to be cost-effective in several cases. In two cases cited by Lal and Thurber (1989), one showed a 50% decrease in disposal and reclamation costs and another had drilling days reduced by over 20% through better waste management. Table 6 illustrates the relative cost of a closed cycle system. Similar cost effectiveness was also obtained in the drilling of a geothermal well. A total of $67 000 (US) was saved, the figure being the difference between total actual cost of the closed cycle system and the estimated cost of sump construction and cleanup (Bell and Hill 1986). This approach is not common in Alberta's oil and gas industry but may be given more attention in the future due to environmental concerns and economic requirements.

Table 6. Comparative Economics for a Typical Well (Bell and Hill 1986).

	1983	1984-5	1986	Closed-loop condition
Surface hole removal efficiency	15%	46%	68%	81%
Production hole removal efficiency	20%	67%	80%	89%
Surface hole mud and disposal costs	$10 200	$7 800	$6 300	$4 500
Production hole mud and disposal costs	$25 600	$14 300	$8 300	$4 800
Total costs	$35 800	$22 100	$14 600	$9 300

Note: Costs are in U.S. Dollars

7. SUMMARY AND CONCLUSIONS

7.1 Burial Methods and Other Options

Disposal of drilling waste by burial can be categorized into four types, ranging from minimal disturbance to total containment of the waste material. Briefly they are:

1. Capping
   - drilling waste solids are minimally disturbed and covered with subsoil and topsoil with or without prior decanting.
2. Mix, Bury and Cover
   - decanted sump contents are mixed with native subsoil material. The waste solids are thus stabilized and diluted before being replaced in the sump and covered with subsoil and topsoil.
3. Trench
   - sump contents are squeezed into narrow, deep trenches and covered with excavated subsoil material.
4. Encapsulate
   - decanted sump contents are totally contained with low permeability liners.

Six alternative options have been identified: land spreading, landfilling, incineration, in-situ solidification/fixation, road application and alkali slough application. Some of these are economically prohibitive while others need further development and refinement to be environmentally acceptable.

7.2 Characterization of Drilling Waste Solids

The most commonly used mud system, freshwater-gel, should have the least adverse impact on the environment. Freshwater-gel mud systems have lower concentrations of soluble salt compared to salt water and invert systems. The hydrocarbon content is also much less than that of the invert mud system. Total heavy metal contents of all three mud types were within the normal range found in soils with the possible exception of molybdenum and zinc.

7.3 Legislation and Policies

Rules and regulations for drilling solids disposal in North America are extremely variable. They range from essentially no written legislation to relatively comprehensive rules and guidelines.

in the United States, several states have more comprehensive regulations than others. they are Alaska, Arkansas, Kansas, Kentucky, Louisiana, Michigan, North Dakota, Oklahoma, and Texas.

In Britain, Italy and the Netherlands, landfill disposal is the most common method. Interestingly, land spreading is either not practiced or is actually prohibited in these countries.

7.4 Applicability of Burial Methods

Table 7 illustrates, at an elementary level, the findings of this study with respect to burial methods of each type of drilling waste solids.

Mix, bury and cover is the most common burial method of disposing of freshwater-gel and salt-based mud waste. In the Northeast Region of Alberta, the following procedure is used for salt-based muds: 1) Sump is dewatered and fluids injected downhole to a disposal formation; 2) Muds are washed 2 to 3 times with fresh water to reduce their salinity. Fluids are injected downhole; and 3) Remaining solids are land spread at a pre-determined loading rate which will permit normal regeneration of vegetative communities. Encapsulation is done only in very special cases. Synthetic liners are generally avoided due to leakage problems (damage to the liner often occurs during installation and sump closure) as well as cost and long term liability.

7.5 Potential Environmental Impacts

As indicated in Table 7, burial of any type of invert mud waste is not considered acceptable. There is no assurance that the oil will be safely contained when buried. The major shortcoming of burying waste which contains hydrocarbons is the slow rate of degradation in the subsoil environment. Soil and groundwater contamination due to migration of invert mud waste have been observed. Land application is the current method of disposal.

Freshwater-gel waste solids are the easiest to handle, store and dispose. It is also the most common mud waste generated in Alberta, comprising over 80% of annual drill waste production. Salt-based (KCl, NaCl) drilling waste solids could be safely disposed of provided that sump site conditions include low permeability soil, a water table deeper than 2 metres below the surface, and poor quality groundwater. Treatment of waste prior to final burial will reduce environmental impacts. Treatment includes: dewatering, prewashing, solids control, mud processing and stabilization.

7.6 Monitoring Requirements

Monitoring programs for buried drilling waste solids are not common in Alberta. Serious contamination problems from burial are not believed common. Only one documented case of long term monitoring (i.e., 3 years) in Alberta was found in the review of literature. Subsidence problems can happen, in which case the current remedial measure is to add more back fill and topsoil or organic amendments. Monitoring requirements are directly related to preplanning and awareness training. Good preventive measures would minimize potential impacts and monitoring requirements.

7.7 Preplanning and Training

The need for preplanning and awareness training was identified by government and industry staff during the information interviews. Such a preventive approach would minimize environmental impact and costs incurred from the disposal of drilling waste solids. Preplanning should give adequate

Table 7. Drilling Waste Solids and Burial Methods in Alberta.

Type	Freshwater-Gel	KCl, NaCl	Invert
CAPPING			
a. w/o decant	X		
b. w decant	X		
MIX, BURY and COVER			
a. surface mix	X	X	
b. sump mix	X	X	
c. deep sump mix	X	X	
TRENCH	X	X	
ENCAPSULATE			
a. clay liner	X	X	
b. synthetic liner	X	X	

Note: X indicates a burial method that may be environmentally acceptable, however, not all of these methods are approved for all regions of Alberta consideration to: mud system selection; waste treatment alternatives; treatment equipment selection and arrangement; sump configuration; location capacity and construction; surface runoff diversion; drilling wastes segregation and disposal options; cleanup; and, restoration requirements. Training would complement preplanning by directly encouraging the understanding and cooperation among drilling personnel with respect to the role and importance they contribute in the various waste handling and disposal processes.

7.8 Conclusion

The information obtained during the study indicates that an unequivocal conclusion as to the environmental acceptability of the burial of drilling waste solids is not possible. The degree of environmental degradation of soil and water resulting from burial is dependent on a number of factors such as: waste characteristics, type of burial method, and most importantly, the geological conditions at the site. Clearly, these factors must be addressed in the formulation of guidelines, which is an evolutionary process, and should be accompanied by research and monitoring of existing sites in order to refine future guidelines.

7.9 Recommendations

It is recommended that:

1. given that directives or guidelines do not exist in Alberta for the treatment or disposal of drilling waste solids, that such directives or guidelines be developed;
2. some of the U.S. states listed in the concluding statement in Section 3.4 should be contacted regarding the rationale and the acceptability of their legislation;
3. one agency should take full responsibility for the coordination and consistency between agencies to ensure compliance of the directives or guidelines;

4. industry should take a more active role in developing the 4 R's of waste management (reduce, reuse, recycle and reclaim) with respect to drilling wastes; and
5. additional information through instrumentation of existing sump pits should be gathered to determine the extent of migration of sump contents through different geological materials; this information would be valuable in determining if, and under what conditions, burial is acceptable.

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RECLAMATION RESEARCH REPORTS

1. **RRTAC 79-2: Proceedings: Workshop on Native Shrubs in Reclamation. P.F. Ziemkiewicz, C.A. Dermott and H.P. Sims (Editors). 104 pp. No longer available.**

The Workshop was organized as the first step in developing a Native Shrub reclamation research program. The Workshop provided a forum for the exchange of information and experiences on three topics: propagation; outplanting; and, species selection. Seven papers and the results of three discussion groups are presented.

2. **RRTAC 80-1: Test Plot Establishment: Native Grasses for Reclamation. R.S. Sadasivaiah and J. Weijer. 19 pp. No longer available.**

The report details the species used at three test plots in Alberta's Eastern Slopes (one at Caw Creek Ridge and two at Cadomin). Site preparation, experimental design, and planting method are also described.

3. **RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp. $10.00**

This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

4. **RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi and H.F. Regier (Editors). 160 pp. $10.00**

Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

5. **RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker and D.F. Polster. 2 vols, 541 pp. No longer available; replaced by RRTAC 89-4.**

Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their suitability for use in reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

6. **RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp. $10.00**

This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

7. **RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stein, R. Leitch and G. Lutwick (Editors). 253 pp. $10.00**

Presents nine technical papers on the chemical, physical, and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites, and use of ash as a soil amendment. Workshop discussions and summaries are also included.

8. **RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp. $10.00**

Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system (in a SPIRES database called RECLAIM). Vol. 2 comprises the keyword index and computer access manual.

9. **RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp. $5.00**

This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available in the Alberta Environment Library.

10. **RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp. No longer available**

Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials.

11. **RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp. No longer available.**

Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

12. **RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz (Editor). 123 pp. $10.00**

Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics, and resulting water quality. Mitigative measures and priorities were also discussed.

13. **RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp. No longer available.**

This is a review and analysis of information on planting stock quality, rearing techniques, site preparation, planting, and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

14. **RRTAC 84-1: Land Surface Reclamation: A Review of the International Literature. H.P. Sims, C.B. Powter and J.A. Campbell. 2 vols, 1549 pp. $20.00**

Nearly all topics of interest to reclamationists including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

15. **RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp. $10.00**

This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

16. **RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

17. **RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser and J.C. Zak. 2 vols, 676 pp. $10.00**

This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

18. **RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz (Editor). 416 pp. $10.00**

Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

19. **RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

20. **RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp. $10.00**

The report examines the critical issue of settling pond design, and sizing and alternative technologies. The study was co-funded with The Coal Association of Canada.

21. **RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp. No longer available.**

Reconstructed soils representing different materials handling and replacement techniques were characterized, and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

22. **RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp. $5.00**

In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

23. **RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp. $10.00**

This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

24. **RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 71 pp. $10.00**

This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

25. **RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp. $5.00**

The report deals with the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is in the Battle River Mining area in east-central Alberta.

26. **RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp. $5.00**

This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

27. **RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

28. **RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp. No longer available.**

This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed. The study was co-funded with The Coal Association of Canada.

29. **RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp. No longer available.**

Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

30. **RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik and D.G. Walker. 174 pp. $10.00**

This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area. The study was co-funded with The Coal Association of Canada.

31. **RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (Compiler). 218 pp. No longer available.**

Technical papers were presented which describe: mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

32. **RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

33. **RRTAC 87-5: Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta. Beak Associates Consulting Ltd. 46 pp. $10.00**

The report reviews existing Alberta guidelines to assess the quality of water drained from coal mine sites in the East Slope Foothills of Alberta. World literature was reviewed within the context of the East Slopes environment and current mining operations. The ability of coal mine operators to meet the various guidelines is discussed. The study was co-funded with The Coal Association of Canada.

34. **RRTAC 87-6: Assessing Design Flows and Sediment Discharge on the Eastern Slopes. Hydrocon Engineering (Continental) Ltd. and Monenco Consultants Ltd. 97 pp. $10.00**

The report provides an evaluation of current methodologies used to determine sediment yields due to rainfall events in well-defined areas. Models are available in Alberta to evaluate water and sediment discharge in a post-mining situation. SEDIMOT II (Sedimentology Disturbed Modelling Techniques) is a single storm model that was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining and is well suited to Alberta conditions. The study was co-funded with The Coal Association of Canada.

35. **RRTAC 87-7: The Use of Bottom Ash as an Amendment to Sodic Spoil. S. Fullerton. 83 pp. No longer available.**

The report details the use of bottom ash as an amendment to sodic coal mine spoil. Several rates and methods of application of bottom ash to sodic spoil were tested to determine which was the best at reducing the effects of excess sodium and promoting crop growth. Field trials were set up near the Vesta mine in East Central Alberta using ash readily available from a nearby coal-fired thermal generating station. The research indicated that bottom ash incorporated to a depth of 30 cm using a subsoiler provided the best results.

36. **RRTAC 87-8: Waste Dump Design for Erosion Control. R.G. Chopiuk and S.E. Thornton. 45 pp. $5.00**

This report describes a study to evaluate the potential influence of erosion from reclaimed waste dumps on downslope environments such as streams and rivers. Sites were selected from coal mines in Alberta's mountains and foothills, and included resloped dumps of different configurations and ages, and having different vegetation covers. The study concluded that the average annual amount of surface erosion is minimal. As expected, erosion was greatest on slopes which were newly regraded. Slopes with dense grass cover showed no signs of erosion. Generally, the amount of erosion decreased with time, as a result of initial loss of fine particles, the formation of a weathered surface, and increased vegetative cover.

37. **RRTAC 87-9: Hydrogeology and Groundwater Chemistry of the Battle River Mining Area. M.R. Trudell, R.L. Faught and S.R. Moran. 97 pp. No longer available.**

This report describes the premining geologic conditions in the Battle River coal mining area including the geology as well as the groundwater flow patterns, and the groundwater quality of a sequence of several water-bearing formations extending from the surface to a depth of about 100 metres.

38. **RRTAC 87-10: Soil Survey of the Plains Hydrology and Reclamation Project - Battle River Project Area. T.M. Macyk and A.H. MacLean. 62 pp. plus 8 maps. $10.00**

The report evaluates the capability of post-mining landscapes and assesses the changes in capability as a result of mining, in the Battle River mining area. Detailed soils information is provided in the report for lands adjacent to areas already mined as well as for lands that are destined to be mined. Characterization of the reconstructed soils in the reclaimed areas is also provided. Data were collected from 1979 to 1985. Eight maps supplement the report.

39. **RRTAC 87-11: Geology of the Highvale Study Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 78 pp. $10.00**

The report is one of a series that describes the geology, soils and groundwater conditions at the Highvale Coal Mine study site. The purpose of the study was to establish a summary of site geology to a level of detail necessary to provide a framework for studies of hydrogeology and reclamation.

40. **RRTAC 87-12: Premining Groundwater Conditions at the Highvale Site. M.R. Trudell and R. Faught. 83 pp. $10.00**

This report presents a detailed discussion of the premining flow patterns, hydraulic properties, and isotopic and hydrochemical characteristics of five layers within the Paskapoo Geological Formation, the underlying sandstone beds of the Upper Horseshoe Canyon Formation, and the surficial glacial drift.

41. **RRTAC 87-13: An Agricultural Capability Rating System for Reconstructed Soils. T.M. Macyk. 27 pp. $5.00**

This report provides the rationale and a system for assessing the agricultural capability of reconstructed soils. Data on the properties of the soils used in this report are provided in RRTAC 86-2.

42. **RRTAC 88-1: A Proposed Evaluation System for Wildlife Habitat Reclamation in the Mountains and Foothills Biomes of Alberta: Proposed Methodology and Assessment Handbook. T.R. Eccles, R.E. Salter and J.E. Green. 101 pp. plus appendix. $10.00**

The report focuses on the development of guidelines and procedures for the assessment of reclaimed wildlife habitat in the Mountains and Foothills regions of Alberta. The technical section provides background documentation including a discussion of reclamation planning, a listing of reclamation habitats and associated key wildlife species, conditions required for development, recommended revegetation species, suitable reclamation techniques, a description of the recommended assessment techniques and a glossary of basic terminology. The assessment handbook section contains basic information necessary for evaluating wildlife habitat reclamation, including assessment scoresheets for 15 different reclamation habitats, standard methodologies for measuring habitat variables used as assessment criteria, and minimum requirements for certification. This handbook is intended as a field manual that could potentially be used by site operators and reclamation officers. The study was co-funded with The Coal Association of Canada.

43. **RRTAC 88-2: Plains Hydrology and Reclamation Project: Spoil Groundwater Chemistry and its Impacts on Surface Water. M.R. Trudell (Compiler). 135 pp. $10.00**

Two reports comprise this volume. The first "Chemistry of Groundwater in Mine Spoil, Central Alberta," describes the chemical make-up of spoil groundwater at four mines in the Plains of Alberta. It explains the nature and magnitude of changes in groundwater chemistry following mining and reclamation. The second report, "Impacts of Surface Mining on Chemical Quality of Streams in the Battle River Mining Area," describes the chemical quality of water in streams in the Battle River mining area, and the potential impact of groundwater discharge from surface mines on these streams.

44. **RRTAC 88-3: Revegetation of Oil Sands Tailings: Growth Improvement of Silver-berry and Buffalo-berry by Inoculation with Mycorrhizal Fungi and N_2-Fixing Bacteria. S. Visser and R.M. Danielson. 98 pp. $10.00**

The report provides results of a study: (1) To determine the mycorrhizal affinities of various actinorrhizal shrubs in the Fort McMurray, Alberta region; (2) To establish a basis for justifying symbiont inoculation of buffalo-berry and silver-berry; (3) To develop a growing regime for the greenhouse production of mycorrhizal, nodulated silver-berry and buffalo-berry; and, (4) To conduct a field trial on reconstructed soil on the Syncrude Canada Limited oil sands site to critically evaluate the growth performance of inoculated silver-berry and buffalo-berry as compared with their un-inoculated counterparts.

45. **RRTAC 88-4: Plains Hydrology and Reclamation Project: Investigation of the Settlement Behaviour of Mine Backfill. D.R. Pauls (compiler). 135 pp. $10.00**

This three part volume covers the laboratory assessment of the potential for subsidence in reclaimed landscapes. The first report in this volume, "Simulation of Mine Spoil Subsidence by Consolidation Tests," covers laboratory simulations of the subsidence process particularly as it is influenced by resaturation of mine spoil. The second report, "Water Sensitivity of Smectitic Overburden: Plains Region of Alberta," describes a series of laboratory tests to determine the behaviour of overburden materials when brought into contact with water. The report entitled "Classification System for Transitional Materials: Plains Region of Alberta," describes a lithological classification system developed to address the characteristics of the smectite rich, clayey transition materials that make up the overburden in the Plains of Alberta.

46. **RRTAC 88-5: Ectomycorrhizae of Jack Pine and Green Alder: Assessment of the Need for Inoculation, Development of Inoculation Techniques and Outplanting Trials on Oil Sand Tailings. R.M. Danielson and S. Visser. 177 pp. $10.00**

The overall objective of this research was to characterize the mycorrhizal status of Jack Pine and Green Alder which are prime candidates as reclamation species for oil sand tailings and to determine the potential benefits of mycorrhizae on plant performance. This entailed determining the symbiont status of container-grown nursery stock and the quantity and quality of inoculum in reconstructed soils, developing inoculation techniques and finally, performance testing in an actual reclamation setting.

47. **RRTAC 88-6: Reclamation Research Annual Report - 1987. Reclamation Research Technical Advisory Committee. 67 pp. No longer available.**

This annual report describes the expenditure of $500,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

48. **RRTAC 88-7: Baseline Growth Performance Levels and Assessment Procedure for Commercial Tree Species in Alberta's Mountains and Foothills. W.R. Dempster and Associates Ltd. 66 pp. $5.00**

Data on juvenile height development of lodgepole pine and white spruce from cut-over or burned sites in the Eastern Slopes of Alberta were used to define reasonable expectations of early growth performance as a basis for evaluating the success of reforestation following coal mining. Equations were developed predicting total seedling height and current annual height increment as a function of age and elevation. Procedures are described for applying the equations, with further adjustments for drainage class and aspect, to develop local growth performance against these expectations. The study was co-funded with The Coal Association of Canada.

49. **RRTAC 88-8: Alberta Forest Service Watershed Management Field and Laboratory Methods. A.M.K. Nip and R.A. Hursey. 4 Sections, various pagings. $10.00**

Disturbances such as coal mines in the Eastern Slopes of Alberta have the potential for affecting watershed quality during and following mining. The collection of hydrometric, water quality and hydrometeorologic information is a complex task. A variety of instruments and measurement methods are required to produce a record of hydrologic inputs and outputs for a watershed basin. There is a growing awareness and recognition that standardization of data acquisition methods is required to ensure data comparability, and to allow comparison of data analyses. The purpose of this manual is to assist those involved in the field of data acquisition by outlining methods, practices and instruments which are reliable and recognized by the International Organization for Standardization.

50. **RRTAC 88-9: Computer Analysis of the Factors Influencing Groundwater Flow and Mass Transport in a System Disturbed by Strip Mining. F.W. Schwartz and A.S. Crowe. 78 pp. $10.00**

Work presented in this report demonstrates how a groundwater flow model can be used to study a variety of mining-related problems such as declining water levels in areas around the mine as a result of dewatering, and the development of high water tables in spoil once resaturation is complete. This report investigates the role of various hydrogeological parameters that influence the magnitude, timing, and extent of water level changes during and following mining at the regional scale. The modelling approach described here represents a major advance on existing work.

51. **RRTAC 88-10: Review of Literature Related to Clay Liners for Sump Disposal of Drilling Wastes. D.R. Pauls, S.R. Moran and T. Macyk. 61 pp. $5.00**

The report reviews and analyses the effectiveness of geological containment of drilling waste in sumps. Of particular importance was the determination of changes in properties of clay materials as a result of contact with highly saline brines containing various organic chemicals.

52. **RRTAC 88-11: Highvale Soil Reconstruction Project: Five Year Summary. D.N. Graveland, T.A. Oddie, A.E. Osborne and L.A. Panek. 104 pp. $10.00**

This report provides details of a five year study to determine a suitable thickness of subsoil to replace over minespoil in the Highvale plains coal mine area to ensure return of agricultural capability. The study also examined the effect of slope and aspect on agricultural capability. This study was funded and managed with industry assistance.

53. **RRTAC 88-12: A Review of the International Literature on Mine Spoil Subsidence. J.D. Scott, G. Zinter, D.R. Pauls and M.B. Dusseault. 36 pp. $10.00**

The report reviews available engineering literature relative to subsidence of reclaimed mine spoil. The report covers methods for site investigation, field monitoring programs and lab programs, mechanisms of settlement, and remedial measures.

54. **RRTAC 89-1: Reclamation Research Annual Report - 1988. 74 pp. $5.00**

This annual report describes the expenditure of $280,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

55. **RRTAC 89-2: Proceedings of the Conference: Reclamation, A Global Perspective. D.G. Walker, C.B. Powter and M.W. Pole (Compilers). 2 Vols., 854 pp. $10.00**

Over 250 delegates from all over the world attended this conference held in Calgary in August, 1989. The proceedings contains over 85 peer-reviewed papers under the following headings: A Global Perspective; Northern and High Altitude Reclamation; Fish & Wildlife and Rangeland Reclamation; Water; Herbaceous Revegetation; Woody Plant Revegetation and Succession; Industrial and Urban Sites; Problems and Solutions; Sodic and Saline Materials; Soils and Overburden; Acid Generating Materials; and, Mine Tailings.

56. **RRTAC 89-3: Efficiency of Activated Charcoal for Inactivation of Bromacil and Tebuthiuron Residues in Soil. M.P. Sharma. 38 pp. $5.00**

Bromacil and Tebuthiuron were commonly used soil sterilants on well sites, battery sites and other industrial sites in Alberta where total vegetation control was desired. Activated charcoal was found to be effective in binding the sterilants in greenhouse trials. The influence of factors such as herbicide:charcoal concentration ratio, soil texture, organic matter content, soil moisture, and the time interval between charcoal incorporation and plant establishment were evaluated in the greenhouse.

57. **RRTAC 89-4: Manual of Plant Species Suitability for Reclamation in Alberta - 2nd Edition. Hardy BBT Limited. 436 pp. $10.00**

This is an updated version of RRTAC Report 80-5 which describes the characteristics of 43 grass, 14 forb and 34 shrub and tree species which make them suitable for reclamation in Alberta. The report has been updated in several important ways: a line drawing of each species has been added; the range maps for each species have been redrawn based on an ecosystem classification of the province; new information (to 1990) has been added, particularly in the sections on reclamation use; and the material has been reorganized to facilitate information retrieval. Of greatest interest is the performance chart that precedes each species and the combined performance charts for the grass, forb, and shrub/tree groups. These allow the reader to pick out at a glance species that may suit their particular needs. The report was produced with the assistance of a grant from the Recreation, Parks and Wildlife Foundation.

58. **RRTAC 89-5: Battle River Soil Reconstruction Project Five Year Summary. L.A. Leskiw. 188 pp. $10.00**

This report summarizes the results of a five year study to investigate methods required to return capability to land surface mined for coal in the Battle River area of central Alberta. Studies were conducted on: the amounts of subsoil required, the potential of gypsum and bottom ash to amend adverse soil properties, and the effects of slope angle and aspect. Forage and cereal crop growth was evaluated, as were changes in soil chemistry, density and moisture holding characteristics.

59. **RRTAC 89-6: Detailed Sampling, Characterization and Greenhouse Pot Trials Relative to Drilling Wastes in Alberta. T.M. Macyk, F.I. Nikiforuk, S.A. Abboud and Z.W. Widtman. 228 pp. $10.00**

This report summarizes a three-year study of the chemistry of freshwater gel, KCl, NaCl, DAP, and invert drilling wastes, both solids and liquids, from three regions in Alberta: Cold Lake, Eastern Slopes, and Peace River/Grande Prairie. A greenhouse study also examined the effects of adding various amounts of waste to soil on grass growth and soil chemistry. Methods for sampling drilling wastes are recommended.

60. **RRTAC 89-7: A User's Guide for the Prediction of Post-Mining Groundwater Chemistry from Overburden Characteristics. M.R. Trudell and D.C. Cheel. 55 pp. $5.00**

This report provides the detailed procedure and methodology that is required to produce a prediction of post-mining groundwater chemistry for plains coal mines, based on the soluble salt characteristics of overburden materials. The fundamental component of the prediction procedure is the geochemical model PHREEQE, developed by the U.S. Geological Survey, which is in the public domain and has been adapted for use on personal computers.

61. **RRTAC 90-1: Reclamation Research Annual Report - 1989. 62 pp. $5.00**

This annual report describes the expenditure of $480,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

62. **RRTAC 90-2: Initial Selection for Salt Tolerance in Rocky Mountain Accessions of Slender Wheatgrass and Alpine Bluegrass. R. Hermesh, J. Woosaree, B.A. Darroch, S.N. Acharya and A. Smreciu. 40 pp. $5.00**

Selected lines of slender wheatgrass and alpine bluegrass collected from alpine and subalpine regions of Alberta as part of another native grass project were evaluated for their ability to emerge in a saline medium. Eleven slender wheatgrass and 72 alpine bluegrass lines had a higher percentage emergence than the Orbit Tall Wheatgrass control (a commonly available commercial grass). This means that as well as an ability to grow in high elevation areas, these lines may also be suitable for use in areas where saline soil conditions are present. Thus, their usefulness for reclamation has expanded.

63. **RRTAC 90-3: Natural Plant Invasion into Reclaimed Oil Sands Mine Sites. Hardy BBT Limited. 65 pp. $5.00**

Vegetation data from reclaimed sites on the Syncrude and Suncor oil sands mines have been summarized and related to site and factors and reclamation methods. Natural invasion into sites seeded to agronomic grasses and legumes was minimal even after 15 years. Invasion was slightly greater in sites seeded to native species, but was greatest on sites that were not seeded. Invasion was mostly from agronomic species and native forbs; native shrub and tree invasion was minimal.

64. **RRTAC 90-4: Physical and Hydrological Characteristics of Ponds in Reclaimed Upland Landscape Settings and their Impact on Agricultural Capability. Moran, S.R., T.M. Macyk, M.R. Trudell and M.E. Pigot, Alberta Research Council. 76 pp. $5.00**

The report details the results and conclusions from studying a pond in a reclaimed upland site in Vesta Mine. The pond formed as a result of two factors: (1) a berm which channelled meltwater into a series of subsidence depressions, forming a closed basin; and (2) low hydraulic conductivity in the lower subsoil and upper spoil as a result of compaction during placement and grading which did not allow for rapid drainage of ponded water. Ponds such as this in the reclaimed landscape can affect agricultural capability by: (1) reducing the amount of farmable land (however, the area covered by these ponds in this region is less than half of that found in unmined areas); and, (2) creating the conditions necessary for the progressive development of saline and potentially sodic soils in the area adjacent to the pond.

65. **RRTAC 90-5: Review of the Effects of Storage on Topsoil Quality. Thurber Consultants Ltd., Land Resources Network Ltd., and Norwest Soil Research Ltd. 116 pp. $10.00**

The international literature was reviewed to determine the potential effects of storage on topsoil quality. Conclusions from the review indicated that storage does not appear to have any severe and longterm effects on topsoil quality. Chemical changes may be rectified with the use of fertilizers or manure. Physical changes appear to be potentially less serious than changes in soil quality associated with the stripping and respreading operations. Soil biotic populations appear to revert to pre-disturbance levels of activity within acceptable timeframes. Broad, shallow storage piles that are seeded to acceptable grass and legume species are recommended; agrochemical use should be carefully controlled to ensure soil biota are not destroyed.

66. **RRTAC 90-6: Proceedings of the Industry/Government Three-Lift Soils Handling Workshop. Deloitte & Touche. 168 pp. $10.00**

This report documents the results of a two-day workshop on the issue of three-lift soils handling for pipelines. The workshop was organized and funded by RRTAC, the Canadian Petroleum Association and the Independent Petroleum Association of Canada. Day one focused on presentation of government and industry views on the criteria for three-lift, the rationale and field data in support of three- and two-lift procedures, and an examination of the various soil handling methods in use. During day two, five working groups discussed four issues: alternatives to three-lift; interim criteria and suggested revisions; research needs; definitions of terms. The results of the workshop are being used by a government/industry committee to revise soils handling criteria for pipelines.

67. **RRTAC 90-7: Reclamation of Disturbed Alpine Lands: A Literature Review. Hardy BBT Limited. 209 pp. $10.00**

This review covers current information from North American sources on measures needed to reclaim alpine disturbances. The review provides information on pertinent Acts and regulations with respect to development and environmental protection of alpine areas. It also discusses: alpine environmental conditions; current disturbances to alpine areas; reclamation planning; site and surface preparation; revegetation; and, fertilization. The report also provides a list of research and information needs for alpine reclamation in Alberta.

68. **RRTAC 90-8: Plains Hydrology and Reclamation Project: Summary Report. S.R. Moran, M.R. Trudell, T.M. Macyk and D.B. Cheel. 105 pp. $10.00**

This report summarizes a 10-year study on the interactions of groundwater, soils and geology as they affect successful reclamation of surface coal mines in the plains of Alberta. The report covers: Characterization of the Battle River and Wabamun study areas; Properties of reclaimed materials and landscapes; Impacts of mining and reclamation on post-mining land use; and, Implications for reclamation practice and regulation. This project has led to the publication of 18 RRTAC reports and 22 papers in conference proceedings and refered journals.

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